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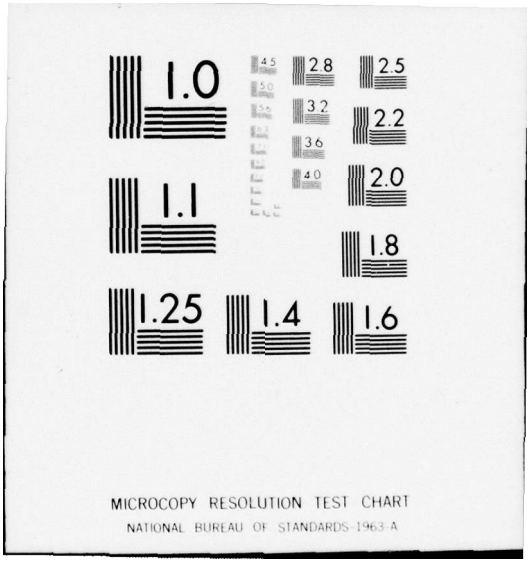
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First Interprofessional Standard For Visual Field Testing

Committee on Vision

Assembly of Behavioral And Social Sciences

Contract No. N00014-75-C-0406

NATIONAL ACADEMY OF SCIENCES

FIRST INTERPROFESSIONAL STANDARD FOR VISUAL FIELD TESTING

FIRST INTERPROFESSIONAL STANDARD FOR VISUAL FIELD TESTING

Report of Working Group 39

Committee on Vision
Assembly of Behavioral and Social Sciences
National Research Council

National Academy of Sciences
Washington, D.C.

1975

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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REMARKS BY CHAIRMAN

Accurate and reliable evaluation of the functional integrity of the visual fields concerns visual scientists of a number of disciplines. The practitioner is interested in visual field measurements in order to diagnose disease, to evaluate the effects of therapy, and to monitor progress. For the practitioner, it is absolutely essential that the data for a given patient be independent of the examiner and the technique of measurement. The evaluation of visual fields is also central to understanding the functioning visual system, whether one is concerned with automobile driving, flying, military observation, athletic performance, or even the simple act of walking across a street.

In view of the multi-disciplinary nature of visual field testing, it is vital that a committee organized to formulate standards comprise scholars with a wide variety of health and academic backgrounds. The membership of the present working group reflects a deliberate attempt by its sponsor to enlist the expertise of a multidisciplinary panel. Under the sponsorship of the NAS-NRC Committee on Vision, this group met three times a year over a period of three years to produce the present document. The privilege of interacting with knowledgeable colleagues in the interest of a problem of mutual concern has been a valuable and enriching experience for all of us. We recognize, of course, that the document represents only an approximation of our goal, but, at the same time we are confident that the recommendations proposed here represent fundamental aspects of standardizing the testing of visual fields. Our ultimate goal can be reached only by the application, empirical testing, modification, and further refinement of these recommendations by health care practitioners, researchers and equipment manufacturers. It is hoped that readers of this document will communicate their reactions to the secretary of the Working Group so that we may broaden the base of this endeavor in pursuit of our mutual interests.

H. W. Leibowitz
June, 1975

FOREWORD

One of the fundamental purposes of standardization in science is to provide a common framework of measurement. Standardization allows exchange and comparison of information obtained at different times and in different places. Standards are also used to provide quality and public safety guidelines for products and procedures. The formulation of standards is the responsibility of three types of groups:

1. Organizations whose standards develop from mutual agreement of representatives of professional, scientific and trade associations, such as the American National Standards Institute.

2. Laboratories established specifically for the purpose of formulating standards, such as the National Bureau of Standards.

3. Regulatory agencies, such as the Federal Aviation Administration.

It has been obvious for some time that a review of standards for testing visual fields is urgently needed. Most available equipment makes use of different test and adaptation conditions. Comparison of results when using different pieces of equipment is relatively difficult (except in the case of gross lesions) and specification of test variables and controls is largely nonexistent. Since visual field testing is conducted in ophthalmological and optometric offices, is widely employed in screening procedures, and is used in selection procedures by various governmental agencies, a mutual effort seemed to be indicated.

This working group is a voluntary action between consenting professional groups and the NAS-NRC Committee on Vision. There is formal representation on the working group from the American Committee on Optics and Visual Physiology (ACOVP) and from the Committee on Research and Standards of the American Optometric Association (AOA). The American Committee on Optics and Visual Physiology is the responsible coordinating body within ophthalmology in the field of optics, visual physiology, and refraction. It has representation from the American Medical Association Section on Ophthalmology, the American Academy of Ophthalmology and Otolaryngology, the Association for Research in Vision and Ophthalmology, and the American Ophthalmological Society. Professors Enoch and Sloan represent ACOVP and Professors Fry and Hofstetter represent the Committee on Research and Standards of the AOA. The remaining members of the Working Group have been appointed by the Chairman in consultation with the ACOVP and AOA representatives. The National Academy of Sciences - National Research Council Committee on Vision provides an effective common focus for this activity, and the Committee can bring to bear special expertise in visual field testing through its constituent members and sponsors.

This committee has participated in the preparation of this document and has approved its publication. Note: the standard comprises only the material contained in the Introduction and Recommendations sections. The remainder of this report provides explanatory, supportive, and educational material. Suggestions for future improvement of this standard will be welcome. Please direct them to the Secretary of Working Group 39. All such recommendations will be considered at the next meeting of the Working Group or at the time of periodic review of the document.

I. INTRODUCTION

Comparisons of visual fields measured by different clinicians or by the same clinician at different times are sometimes difficult to make. Frequently, testing conditions are either unspecified or expressed in unsuitable units. In fact the limited standards that are quoted are often specified in unsuitable units. Such conditions inhibit accurate measurement and exchange of data. In this report we seek to overcome this problem by setting forth an initial outline of conditions which will yield reliable and meaningful measurements of visual fields. We feel that an effort ought to be made towards defining guidelines for test conditions and methods, with some uniform scheme for reporting test results. If standardization can be achieved, perhaps the newer and more sensitive test procedures will become more widely used in the evaluation of the visual field, leading, we hope, to earlier and more definitive diagnosis of abnormal visual function.

We distinguish between a standard for the practitioner in the office, where limited calibration equipment and support facilities exist and a standard for the advanced research or clinical laboratory. This document is written primarily for the benefit of the practitioner and deals with equipment used by the practitioner. The office or small laboratory must be provided with standards that can be readily applied, that require only a small amount of calibration equipment and a short time for evaluation, and whose tolerances are set within a range of values so that modest errors do not markedly alter test results. The last point means that evaluations should be conducted under conditions that can vary reasonably without changing the test results very much, a topic that will be discussed in more detail later. We assume that equipment for precision testing will be concentrated at regional test centers and that, except under unusual circumstances, such devices and techniques will not generally be available to the office-based ophthalmic practitioner nor to organizations doing routine selection or screening.

We encourage the clinician to improve the quality of his equipment and procedures for testing visual fields as recommended in this document. We feel that it is the responsibility of the manufacturer to provide the clinician with equipment (plus data regarding that equipment and suitable calibration devices) meeting our recommendations. We expect the ophthalmic academic community to teach the use and calibration of devices supplied. We ask the practitioner to maintain the calibration of his equipment and to record pertinent test conditions employed.

Only limited goals have been set in this report. At this time we are satisfied with improved specification of visual stimuli. We hope in the future that optimal test conditions may be defined and that common reporting procedures and deficiency evaluation schemes may be formulated. Other pertinent research goals are defined below.

II. RECOMMENDATIONS

1. That photometric standards for visual field test equipment be expressed in luminance units; that the illuminant and its desired operating characteristics be specified by the manufacturer for each visual field testing device.

The limited standards available for tangent screen testing are expressed in terms of illuminance falling on the tangent screen (7 foot candles).* However, guidelines make no mention of the reflectance of light from the screen and the test targets toward the eye, nor of the contrast of the test target with the background. Further, adequate (and calibrated and stabilized) light sources are often not provided with test equipment.

The purpose of the tangent screen or other visual field testing device is to determine the sensitivity of the visual system at different loci to luminous stimuli of given sizes, configurations and durations. Since the intent is to determine visual response to light, any given determination is only as meaningful as the accuracy of the definition of the luminous stimuli. An adequate, stable and calibrated illuminant (or illuminants) is (are) an essential component(s) of any visual field testing device.

Luminance of the test object and background field, measured at the center of the entrance pupil of the eye, should be specifiable as well as the preferred test distance. ** Luminance is defined as luminous flux emitted per unit solid angle per unit projected area. The product of luminance (measured at the center of the entrance pupil of the eye) and the area of the entrance pupil of the eye provides an estimate of retinal illuminance (luminous flux per unit area falling on the retina), the visual stimulus. It is not practical to control pupil area in routine visual field testing, and since pupil area is effectively reduced for oblique angles of incidence, the best that can be achieved is to specify luminance in the center of the entrance pupil of the eye and ask that entrance pupil size be recorded.

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* An unofficial standard illuminance value of 7 foot-candles falling on the test surface has often been used. See Thomasson, 1934.

** For extended uniform fields, stimulus magnitude is independent of test distance. This does not hold for the smaller (approaching point objects) test targets used in perimetric and tangent screen testing (see Table II). Hence, preferred test distance should be specified.

The international unit of luminance is the candela per square meter (cd/m^2), also called the nit. The advantage of this unit is that it is not bound by special surface reflectance properties. If the test target area or the background surface approaches a perfectly diffuse reflecting surface, millilambert or apostilb units may be used.* In such a case, 1 millilambert = 3.183 candelas/m^2 (nits), and 10 apostilbs = 1 millilambert. Note, $3.183 = 10/\pi$. German-speaking manufacturers have tended toward the use of the apostilb (international) in recent years. In the United States the millilambert is the most commonly used unit of luminance. Since 1 millilambert = 10 apostilbs, these units are readily interchanged. The great convenience of the millilambert and apostilb units is the simple relation of these units to units of illuminance (see section IV. A. 1.).

While this Working Group would prefer direct measurement of luminance in calibration of visual field testing devices, an acceptable alternative would be to provide a measure convertible into luminance at the center of the entrance pupil of the eye.

For a more complete discussion of the specification of luminance and other photometric quantities, the reader is directed to the most recent edition of the Handbook of the Illuminating Engineering Society, Illuminating Engineering Society, Fifth Edition, N. Y., 1972. The matter is also discussed in section IV. A. 1. of this report.

To facilitate the comparison of data obtained on different instruments, we ask that the manufacturer define the recommended background and test target luminance levels in candelas/m^2, and if applicable, give the conversion in millilamberts and apostilbs (international). Note that there are two different sets of apostilb units; only the international unit should be used.

While light sources may have quite different spectral compositions: there are many "whites", some bluer, other yellower and redder. To aid in comparison of data obtained on different instruments, it is desirable that each manufacturer specify the light source, the wavelength composition of its spectrum (e.g., the color temperature), the desired operating conditions, accessory filters (if employed), and a simple scheme for determining when a particular light bulb should be replaced.

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* Strictly speaking, the dimension of a millilambert or apostilb unit (lumens per unit area) are those of a unit of exitance. However, since in the special case of a diffuse reflecting surface, luminance is proportional to exitance, exitance units may be used for specifying luminance.

Information on the wavelength composition of stimuli reaching the eye should be supplied by the manufacturer whether or not the visual field testing device provides test material for evaluating "color" fields, since a practitioner may wish to test "color" fields at some future date and would find it difficult to do so without this information.

2. That in the specification of chromatic stimuli, the wavelength composition of the stimulus reaching the eye and the C.I.E. (Commission International de l'Eclairage) chromaticity coordinates be given.

The control of test parameters in visual field testing is often unsatisfactory when using white light (except with some of the newer quantitative perimeters); the situation is even more disappointing when one considers the status of "color" fields or tests designed to evaluate chromatic sensitivity at various points in the visual field. Except for the work of Ferree and Rand and a few other outstanding investigators, most of the clinical literature in this area is hopelessly confused, the main reason being that the visual stimuli employed have not been adequately defined. Which red? What luminance? How saturated? What is the effect of color contrast and luminance contrast of the target with the background? What is the effect of using fluorescent paints on targets? The answers to these questions are not available at the present time.

Color vision is extremely sensitive and its various mechanisms may be isolated for study. Hue detection, hue matching, and hue discrimination thresholds have been evaluated. More recently, attempts have been made to isolate fundamental color mechanisms using techniques defined by Stiles. For further discussion on this problem, see section V. C.

If progress is to be made and the promise of these newer methods realized, targets, luminous stimuli, and backgrounds must be specifiable in accepted colorimetric terms (C.I.E.). Then clinical findings can be effectively compared with the results of different investigators in the vast literature on normals. Since the chromatic properties of stimuli (test and background fields) may be altered by changing the source and by interposing filters, or by altering the reflecting surface, the wavelength composition of each stimulus should be specified at the eye. For purposes of replacement at a later date, the transmission properties of filters and light sources and the reflectance properties of papers and paints employed should be indicated.

3. That background field luminance, test target parameters /target luminance, size (area), configuration, and exposure duration or rate of translation/, viewing distance, and location of a target in the visual field be specifiable. (see also Recommendation no. 4).

Background Luminance

The luminance of the extended background in a field testing apparatus should be specifiable and a means for specifying it should be provided by the manufacturer. The background field helps establish the adaptation state at which the test is conducted. The test apparatus should be shielded from other light sources and a manufacturer's recommended pre-test adaptation period should be of sufficient duration to provide a stable visual response. Note that light adaptation takes only a few minutes: black and grey tangent screens and perimeters provide low luminance adapting fields.

Every effort should be made in design of equipment to provide a uniform background field (tangent screen, cupola, etc.) which would ensure constancy of adaptation - even if fixation is altered periodically. Without uniformity in the background, different retinal areas are subject to variations in adaptation level such that the contrast of the target with the background and its visibility may fluctuate across the field. An example of such a situation is found in offices equipped with a tangent screen illuminated by a single ceiling lamp located close to the tangent screen. Since the upper part of the screen receives far more light than the lower portion, the usual result is an apparent constriction of isopters in the inferior visual field! It should be emphasized that a uniformly illuminated background field does not provide equal illumination across the retina; rather, it provides a controlled test condition and generally yields minimized variability in test results.

Several factors influence peripheral retinal illuminance: the relative transmittance of the optical surfaces of the eye with oblique incidence; the apparent foreshortening of the pupillary aperture in one meridian with oblique entry of light; the varying absorption characteristics of the ocular media; the quality of the image formed on the peripheral retina (which influences target rather than background) and the relative reduction in the distance between the center of the exit pupil and the retina in the periphery.

Test Target Parameters

The detectability of a test target is affected by a number of variables. Target luminance and its resulting contrast with the background, the angular size of the target (preferably specified in terms of visual angle subtended and test distance), and the shape of the target are known to influence visibility and need to be specifiable. Since the retina is sensitive to changes in the test stimulus both in space and in time, the possibility of specifying duration of target exposure or the desired rate of translation also need to be provided by manufacturers.

The diameter and distance of the test target (in millimeters) have traditionally been described in tangent screen studies as a fraction*,

* This fraction is the tangent of the visual angle subtended by the target at the eye, assuming the target is located at the center of the tangent screen.

which may be used as a specification of visual angle. Newer instruments have specified the target in terms of both the visual angle subtended and the test distance. While the older system is acceptable, the later form is gaining popularity and is encouraged.

A few words of caution, however: One of the least appreciated variables in visual field testing is target blur, both in the central and peripheral field. Data obtained at different test distances are subject to variability due to uncorrected refractive errors (adjusted for the test distance), presbyopia and effects induced by cycloplegics and miotics. The later pharmaceutical agents alter pupil size, image quality, retinal illuminance, and adaptation level. In the presence of cataract, variation of pupil size may markedly influence induced stray light effects. A record of entrance pupil size and correction placed before the eye during a visual examination is a desirable part of the test record.

Location and Angular Size of a Target in the Visual Field.

The angular position of a target in the visual field and the angular size of a test target should be specified relative to the center of the entrance pupil of the eye and the primary line of sight. The entrance pupil is the image of the center of the iris aperture as seen through the cornea. A corrective lens alters the situation: The closer a corrective lens is placed to the eye, the less the entrance pupil is displaced optically and the larger is the visual field available for testing through the correction. The primary line of sight is the ray connecting the point of fixation and the center of the entrance pupil of the eye. Thus, one might specify the visual threshold for a round target having a diameter of 10 minutes of arc (an area of 78.5 square minutes of arc), located with an eccentricity of 10° from the point of fixation (zero reference) on the 120° half-meridian. The 0° half-meridian is defined as the horizontal line to the right of the fixation point of the patient and should be located at the same height as the interpupillary line. The half-meridian angle is measured counter-clockwise relative to the patient's point of reference. This scheme reflects the format currently being used by a large number of manufacturers (there are exceptions, e.g., T. Hamblin, Ltd.). It should be noted that the designation of the half-meridian is opposite to that used when recording the cylinder axis in spectacle correction. In that case, the zero half-meridian is to the patient's left, and the cylinder axis proceeds clockwise relative to the patient's point of reference. Similarly, the recommended scheme departs from some systems used when referring to ophthalmoscopic views of the fundus and contact glass observation systems (e.g., Plange, 1971). A scheme has been suggested by Fry (1959) that, in essence, would put the recording of visual field meridians in accord with the cylinder axis system used for spectacle corrections. A single, organized angular reference system would clearly be desirable for all such designations.

4. That office, field, and screening instruments design incorporate test parameters that produce relatively stable response states.

Instruments designed for wide use must be stable in their operating properties. For example, one might like to test visual response for exposures shorter than the critical duration, that is, to determine visual response during that very brief period of time when response is dependent upon total energy impinging on a retinal test area of a specific size (e.g., Graham and Margaria, 1935; Owen, 1972). In order to test response to brief stimuli, one must have precise control over a flash system or a mechanical or electro-optical shutter device. Such devices tend to go out of calibration with repeated use. Thus it is best to design visual field test instruments for exposures exceeding the critical duration value (ca. 100 msec) but below that of the latency of an eye movement (ca. 250 msec). If there is an error of 10 - 20% in flash duration when the test stimulus exceeds the critical duration by a reasonable margin of time, visual performance is not altered.

As another example of a stable response state, it is probably best to set the background luminance level within the range for which the Weber Fraction remains constant. The Weber Fraction is defined (for these purposes) as the increment threshold luminance (or static threshold) divided by background luminance. In the range for which the Weber Fraction is constant, the measured field is not particularly altered by the partial darkening of an aging light source or by modest variations in pupil size. When such factors significantly affect the Weber Fraction, false changes in isopter dimensions or recorded thresholds may be found. While a transitional state such as the mesopic may provide more sensitive clues to early anomalies, to hold this level of adaptation properly can be difficult (good calibration equipment is needed). Similarly, in the mesopic response range, better control of the patient's adaptive state and pupil size is required. More sensitive tests may be accomplished at regional centers or research laboratories.

Recently designed perimeters have successfully employed background luminance levels in the range 3.18 to 10.03 cd/m^2 (1.0 to 3.15 millilamberts, 10 to 31.5 apostilbs). This Working Group does not wish to propose a single value of background luminance level for quantitative perimeters as standard at this time, rather we hope to see the results of further research before proposing some single level or a range of optimal test conditions. Pending such information, it would seem prudent for manufacturers of new equipment to use background luminance levels within the range given above. (see also section IV. A. 3.). When a standard condition is defined, equipment should have provision for variation of test parameters in order to provide the examiner with some choice and to allow correction for extreme variation in pupil size (e.g., the patient being treated with phospholine iodide or atropine). Thus a standard is viewed by this committee as a minimum condition, not as a limiting condition.

III. RECOMMENDATIONS FOR THE FUTURE

Clearly this Working Group favors greater utilization of what has come to be called quantitative perimetry. We are well aware, however, of the problems of cost, instrument availability, time required for patient examination, the limited pool of trained individuals available to operate such devices, and the mixed array of visual field testing equipment currently used in thousands of ophthalmic offices. For these reasons we do not advocate precipitous change.

In this document we call for more detailed specification of stimulus parameters and general improvement of equipment. In line with this objective, we urge a trend toward quantitative perimetry, a trend that is already reflected in recent reports in the ophthalmic literature and in the offerings of manufacturers to the ophthalmic community. We hope that equipment will indeed be provided that will permit improvement of instruments already in the field. We strongly encourage the following lines of research.

a. An organized effort should be made to define optimal test conditions for routine visual field examination.

b. An attempt should be made to find means of minimizing observer (patient) variability during testing and maximizing examiner performance in an effort to improve the reliability of the test procedure.

c. Efforts should be directed toward at least partially automating visual field testing in order to provide wider coverage to specific target populations who require screening or who may be at risk (see section VI. D.).

d. Rational schemes for reporting visual field loss for a given target should be developed following up the initial work of Esterman (1967, 1968).

e. In view of our greatly enhanced understanding of neural data processing at a number of levels along the visual pathways, it is desirable that methods be developed allowing evaluation of local response capabilities in line with these new findings. To the greatest extent possible, new techniques should be adapted to available visual field testing equipment in an effort to enhance diagnoses and more finely localize anomalies.

Since this is but a first step, we recommend reconvening this Working Group in five years to reconsider the continual upgrading of visual field test standards.

IV. BASIC FACTORS IN VISUAL FIELD TESTING*

Techniques to measure perception are indirect and usually concentrate on some response that is a consequence of subjective experience. Such a response might be the spoken words "I see the target" or pushing a button. Many factors determine whether such responses will be given following the presentation of a visual stimulus: the physical characteristics of the stimulus (the distal stimulus), pre-retinal characteristics of the eye, the actual light striking the retina (proximal stimulus), receptor and neural mechanisms of the retina and of the brain, and psychological factors. Table 1, prepared by Greve (1973), lists the specific variables in each category.

A. Stimulus Factors

1. Luminance

Luminance is defined as luminous flux emitted by a surface per unit solid angle per unit projected area. The international unit of luminance is the candela per square meter (cd/m^2), also called the nit. This unit is independent of surface reflectance properties and is measured with respect to the center of the entrance pupil of the eye. If, and only if, a reflecting surface is perfectly diffuse, the luminance may be expressed in millilambert or apostilb units ($lumens/m^2$). One cd/m^2 equals $\pi/10.0$ millilamberts; 1.0 cd/m^2 equals π international apostilbs. Since 1.0 millilambert, which is widely used in the United States, equals 10.0 apostilbs, popular in Northern Europe, conversion between these two units is simple. The convenience of the apostilb units is their simple relationship to the illuminance falling onto a perfectly diffuse surface:

$$L = E \times R,$$

where L is the luminance in apostilbs, E the illuminance in meter-candles (or lux), and R the reflectance of the surface. The same relationship holds when L is expressed in foot-Lamberts and E is in foot-candles.

The actual stimulus for visual excitation is the image on the retina, called the proximal stimulus. The luminous flux per unit area falling on the retina (retinal illuminance) is determined by the

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* Editor's note: Sections I, II, and III contain the recommendations of the Working Group. The following sections (IV, V, and VI) summarize the findings from visual science on which the recommendations are based and provide a general survey of the factors that should be considered when making perimetric measurements.

Table 1

Factors that Determine the Level of the Difference Threshold

Physical Characteristics of Stimulation	Preretinal Factors	Stimulation at the Retinal Level	Receptor and Neural Mechanisms	Psychological Factors
Position of the stimulus in the perimeter	Pupil size Transparency of ocular media, Ametropia, and Accommodation	Position of the stimulus on the retina	Anatomical differences in the visual system	Understanding Interest Cooperation Fear Training
Level of luminance before the examination		Retinal illumination before the examination: preadaptation level	Adaptation	
Contrast background luminance stimulus luminance		Retinal contrast retinal illumination by the background, ambient illumination retinal illumination by the stimulus	Spatial interaction	General health
Stimulus size Stimulus sharpness		Size and shapeness of the image		
Presentation time			Temporal interaction Local adaptation	Reaction time
Movement			Sensitivity to movement of the visual system	
Chromaticity of the stimulus		Retinal chromaticity	Specific sensitivity for wavelength	
Fixation target			Conditions of fixation	

luminance of the distal stimulus and pre-retinal factors such as pupil size and transparency of the cornea, lens, and ocular media. Retinal illuminance can be estimated by the following relationship:

$$Td = L \times S,$$

where Td is the retinal illuminance in trolands, L is the stimulus luminance in cd/m^2 and S is the pupillary area in square millimeters. Thus, in order to obtain an estimate of the proximal visual stimulus, the diameter of the pupil must be known. For extended surfaces, retinal illuminance is independent of viewing distance. For optical reasons, this independence does not hold if viewing distance becomes so great, or the size of a test target becomes so small, that it subtends, at the eye, a visual angle less than about 6 minutes of arc (a 1 mm disk, viewed at a distance of 1000 mm, subtends an angle of 3 minutes 26 seconds). For such tiny targets, the luminance of the proximal stimulus is not independent of viewing distance.

In addition, when the pupil is large, one needs to be aware of the directional sensitivity of the retina (the Stiles-Crawford effect), for peripheral pupillary zones are less effective in stimulating a response than the central pupillary area in the normal individual at photopic levels. This factor is generally overlooked in clinical work.

2. Target Luminance and Contrast

The purpose of a perimetric or tangent screen examination is to determine the sensitivity of the visual system at different loci in the visual field to luminous stimuli of specified size, shape, and duration. The minimum amount of luminance required to detect a target presented against a completely dark background is a measure of the absolute threshold. More frequently, a target is presented against a background of some luminance. In this case, the amount of target contrast required for detection of the target is called the increment threshold or the luminance difference threshold.* Target contrast is often defined:

$$C = \frac{L_t - L_b}{L_b} = \frac{\Delta L}{L_b},$$

where L_t is the luminance of the test target and L_b is the luminance of the background upon which the target is presented. The difference between the target and background luminances is expressed as ΔL. Contrast sensitivity is expressed as the reciprocal of the threshold contrast ($1/C + L/\Delta L$). In order, therefore, to specify contrast sensitivity, the luminance of both the test target and its background must be known and controlled.

* In the English literature the term "liminal brightness increment" is often used.

There are six important stimulus variables that will determine whether a circular* target will be detected against a uniform background at a given retinal locus; its angular size, its contrast with the background, the difference in chromaticity between target and background, the luminance of the background, the duration of the target exposure, and blur of the retinal image. If we can assume a well-focused image, changes in the values of one variable may be offset by changes in another (within limits). For example, a target ten minutes in diameter, exposed for a duration of 10 msec, will require a certain contrast to be detected. If its diameter is reduced to 5 minutes of arc, it will no longer be visible. It can be restored to visibility, however, by increasing either its contrast or its exposure duration. Of these variables, it must be stressed that contrast is the dependent variable that one measures in order to specify contrast sensitivity; the others are independent variables whose values greatly affect threshold contrast, and, in any rigorous technique of clinical perimetry, it is desirable that they be carefully controlled.

The effects of angular size, exposure duration, and background luminance on detection sensitivity have been intensively studied for foveal vision, but less is known about the effects of these variables on peripheral vision. The main effects of these three variables are discussed below.

3. Background Luminance

The luminance of the background on which the target is presented has a profound effect on the target's contrast threshold. As the background is increased from the lowest scotopic luminance of 3.2×10^{-13} cd/m^2 (10^{-12} asb) (estimated by Aulhorn, Harms, and Raabe, 1966, to be the equivalent of a completely dark background) through the mesopic level of about 3.2×10^{-3} cd/m^2 (10^{-2} asb) into the lower photopic luminances, the contrast threshold for detection of a target is progressively reduced, i.e., contrast sensitivity increases. Figure 1 shows the effect of background luminance on contrast threshold for foveally viewed targets ranging in angular diameter from 6.6 to 56 minutes of arc. Above the background level of 100 trolands (with a 4mm pupil diameter, 100 Td corresponds to a background luminance of 8 cd/m^2 or 25 asb) little change in contrast threshold occurs. At these higher photopic levels of background luminance, the contrast threshold approaches Weber's Law where $\Delta L/L_b$ = constant. Aulhorn and Harms (1972) have estimated that background luminance above which Weber's Law holds to be about 32 cd/m^2 (100 asb). In the periphery of the visual field, even higher background luminances are necessary for Weber's Law to be valid (see Aulhorn and Harms, 1972, Figure 15). All such evaluations assume constant pupil size. If pupil size changes, these values become altered.

* The threshold contrast for moderately elliptical targets is the same for circular targets of equivalent areas. The circular equivalents of the elliptical targets of the Goldmann perimeter are given in Table 3.

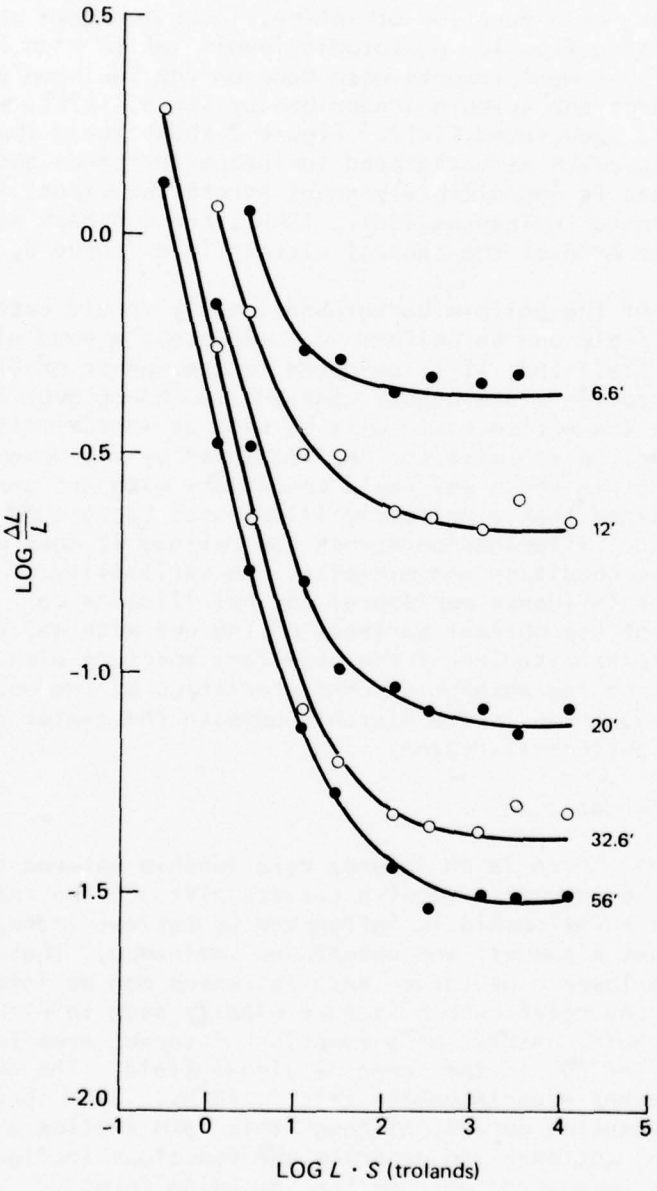

Figure 1. Foveal contrast threshold as a function of retinal illuminance for circular test targets of different diameter. Exposure duration is 30 msec. (from Graham and Bartlett, 1940, reprinted with permission)

Figure 2 presents contrast sensitivity for a target, 10 minutes of arc in diameter, as a function of retinal locus for five background luminances ranging from low phototopic levels (a) to high scotopic levels (e). These measurements were made on the Tübingen perimeter designed by Harms and Aulhorn (described by Sloan, 1971), which provides a hemispherical background field. Figure 2 shows again that contrast sensitivity increases as background luminance increases and that the rate of increase is approximately equal across the visual field. At mesopic background luminances (Bair, 1940), the contrast sensitivity is uniform over much of the central visual field (curve d, Figure 2).

The size of the uniform background ideally should extend over the entire visual field and be uniform in luminance. A dome will provide a hemispherical field and, if illuminated in the manner of Ulbricht's sphere, will provide a reasonably constant luminance over its surface. In this manner the entire field will be held at approximately the same adaptation level, which will not be influenced by eye movements. It is difficult to obtain these desirable conditions with arc perimeters. It must be emphasized that a uniformly illuminated background field does not provide equal illumination across the retina; it does provide a controlled test condition and minimizes the variability of test results. Several factors influence peripheral retinal illuminance: the relative transmittance of the optical surfaces of the eye with oblique incidence, the apparent foreshortening of the pupillary aperture with oblique entry of light, the varying absorption characteristics of the ocular media, and the relative reduction in the distance between the center of the exit pupil and the peripheral retina.

4. Target Size

In general, there is an inverse relationship between threshold contrast and the angular size of a target, although the exact mathematical nature of this relationship is influenced by retinal locus, exposure duration, target diameter, and background luminance. That contrast thresholds are lowered as target area increases can be inferred in Figure 1, but the relationship is more clearly seen in Figure 3, which presents threshold contrast as a function of target area for the fovea, 5°, 10°, 40°, and 60° in the temporal visual field. The curves of Figure 3 represent area-intensity relationships. Such curves have been called summation curves, although this term implies a theoretical interpretation. Attempts to describe the functions in Figure 3 as straight lines have usually taken the following form:

$$\Delta L \times A^{k} = \text{Constant},$$

where ΔL equals the difference threshold, A equals the area of the target and k equals a constant (the slope of the function) for a small segment of the curve.

The exponent k is sometimes referred to as the summation coefficient. When there is complete reciprocity and the threshold depends only on the total amount of light in the test area, k is equal to 1.0.

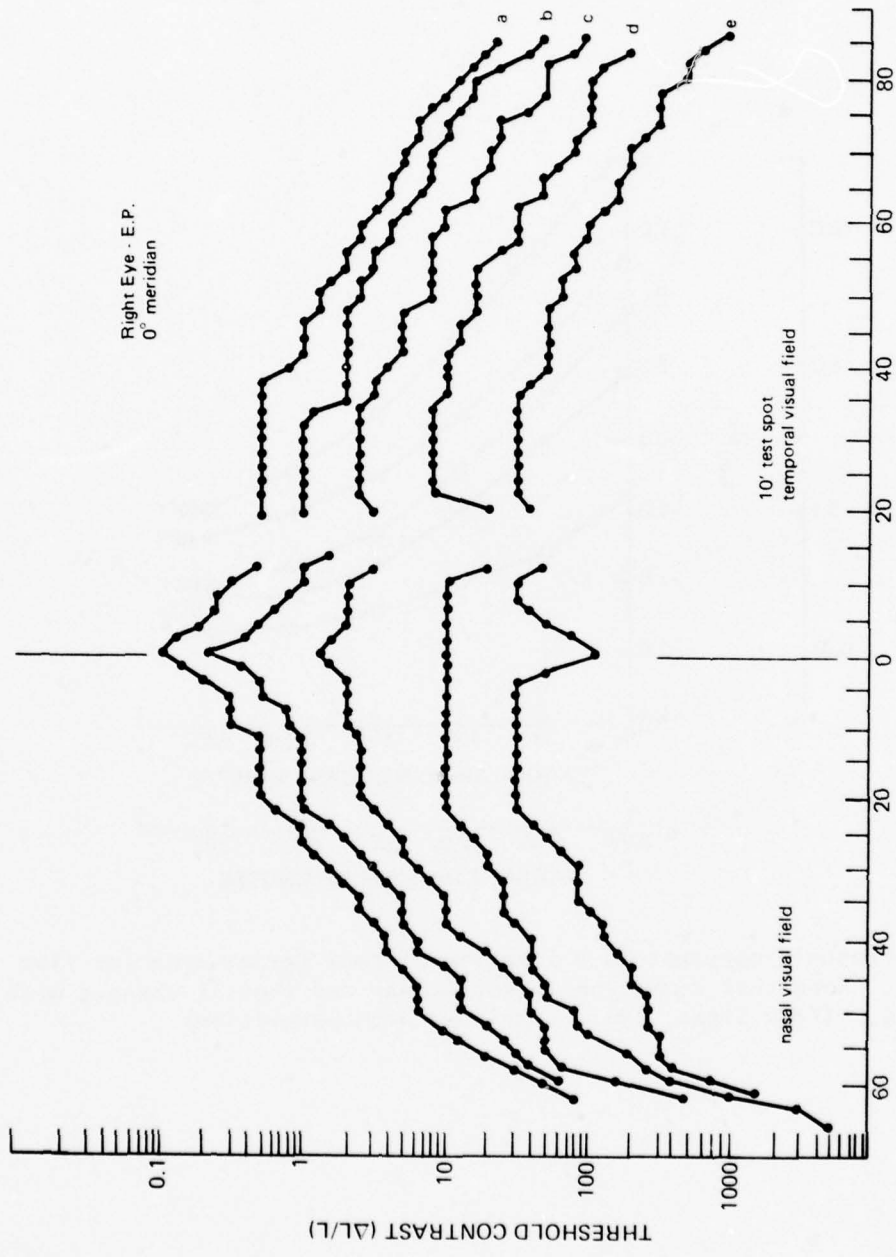

Figure 2. Contrast threshold as a function of retinal locus for different background luminances. a=2.7 cd/m^2; b=0.27 cd/m^2; c=0.027 cd/m^2; d=0.0027 cd/m^2; e=0.00027 cd/m^2. Note that the ordinate represents sensitivity. (from Harvey and Pöppel, 1972, reprinted with permission)

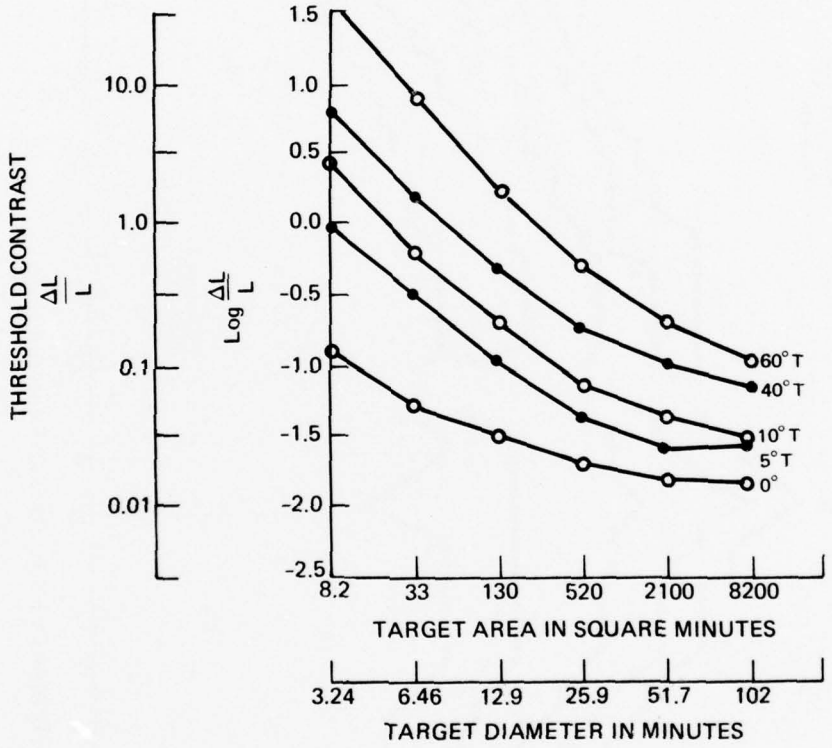

Figure 3. Threshold contrast as a function of test target area for five retinal loci. Note that summation is not linear and that it changes with retinal locus. (from Sloan, 1961, reprinted with permission)

When threshold does not change with changes in target area, k equals zero. The usual finding is that k is greater than zero but less than one, indicating less than perfect reciprocity. When k equals 1.0, the relationship is known as Ricco's Law. Ricco's Law is found to describe data only from very small targets (generally less than 10 minutes of arc in diameter). Figure 3 clearly shows that a straight line does not describe the data well. Rather the value of k changes as a function of target size.

For clinical purposes, however, it can be of some value to estimate the spatial summation properties of a given retinal locus. One can estimate k for a given part of the visual field by measuring the contrast threshold for two targets that differ in area by a known amount. The successive targets of the Goldmann perimeter for example vary in area by a factor of 4.0. Exponent k can then be estimated by:

$$k = \frac{\log \Delta L_2 - \log \Delta L_1}{\log A_1 - \log A_2}$$

Static perimetric studies (Fankhauser and Schmidt, 1958, 1960; Sloan, 1961; Dannheim and Drance, 1971) have shown variation in the values of k among individuals. Reciprocity holds over a wider range of test areas for low background luminance than for high (Fankhauser and Schmidt, 1960; Dannheim and Drance, 1971). Although contrast sensitivity is reduced with age, the shape of the areal summation curve is unaffected (Dannheim and Drance, 1971). The exponent k for a given range of target areas increases from center to periphery and for a given retinal location is less for large than for small test targets. Since Figure 3 indicates that the slopes of the area-intensity curves are not constant, care must be used in interpreting any specific value of k, since its value will depend on the actual target sizes used to derive it.

5. Target Duration - Temporal Summation

The duration of target exposure greatly determines how much contrast will be required to detect it. In fact, for short exposures there is an inverse relationship between exposure duration and target luminance such that:

$$\Delta L \times T = \text{Constant} \quad \text{(Bloch's Law)},$$

Figure 4 presents total energy at threshold ($\Delta L \times T$) as a function of exposure duration (T) for various background luminances. Figure 4 shows that for short durations, threshold energy is constant. This perfect reciprocity is found only for targets smaller than the spatial summation area; for larger targets, slight deviations from reciprocity are found (Owen, 1972). As exposure duration is increased, the reciprocal relationship eventually breaks down. The duration at which reciprocity no longer holds is called the critical duration. Its value depends on background luminance and is about 30 msec for the highest luminance of Figure 4 and about 100 msec for the lowest. For exposures longer than the critical duration, laboratory studies indicate that threshold energy (or threshold contrast) is independent of exposure duration (i.e., ΔL = constant).

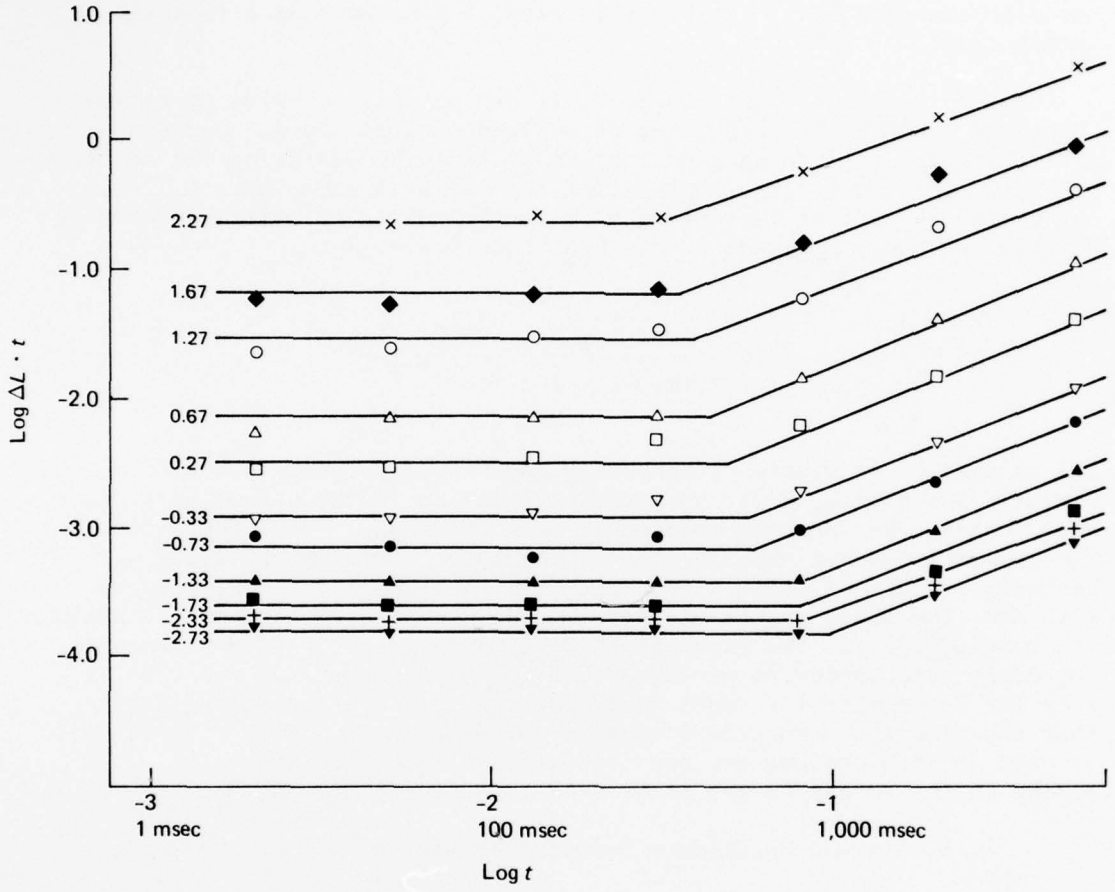

Figure 4. Total stimulus energy (ΔL x T) at threshold as a function of exposure duration for various background luminances. (from Graham and Kemp, 1938, reprinted with permission)

This independence may not be valid for clinical perimetry where eye movement and pupil size usually are not well controlled. Figure 5 presents the data of Dorff (1953), who studied the effect of exposure duration on detection threshold in static perimetry at eight levels of background luminance. His data show that maximum sensitivity at each retinal locus and at each background luminance is reached at a stimulus duration of at least one second. These results suggest that further work would be desirable.

The latency of a saccadic eye movement is between 180 - 250 msec (Enoch, Goldmann, and Sunga, 1969) and can be a significant factor, influencing measurements where a tendency toward unsteadiness of fixation exists. For clinical perimetry an exposure duration shorter than eye movement latency and longer than the critical duration is desired. Setting the duration longer than the critical duration is desired to avoid variability associated with mechanical shutters.

B. Response Factors

1. General Considerations

Most of the basic psychophysical data previously discussed have been obtained with experienced observers. By using experienced observers, problems associated with practice are eliminated so that variability of responses is reduced. The clinical assessment of visual fields, however, usually involves naive observers. Many patients are serving for the first time in what, in effect, is a difficult psychophysical experiment and may be anxious or apprehensive about the examination. Psychophysical experiments generally have rigorous control over the stimuli but often neglect response variables that will affect a patient's performance, e.g., instructions, patients's expectations, rewards, and examiner personality. The term "demand characteristics" has been used to refer to such response variables. (Miller and Leibowitz, in press).

2. Detection Behavior

When one asks the seemingly simple question, "How much physical energy is needed for a person to detect a stimulus?" one quickly sees that both the question and the answer are complex. There is no single energy above which a stimulus will always be detected and below which it will never be detected. Instead, there will exist a range of physical energies over which the probability that the stimulus will be detected is less than one and greater than zero. The probability of detection as a function of stimulus energy is described by the familiar psychometric function, which typically has the sigmoid shape shown in Figure 6.

The "threshold" energy is defined as the energy that will give a particular probability of detection. It is a statistical convention. Usually the threshold value is taken as the energy at a detection probability half-way between chance performance and 100% detection, although other criterion values are occasionally used for theoretical reasons.

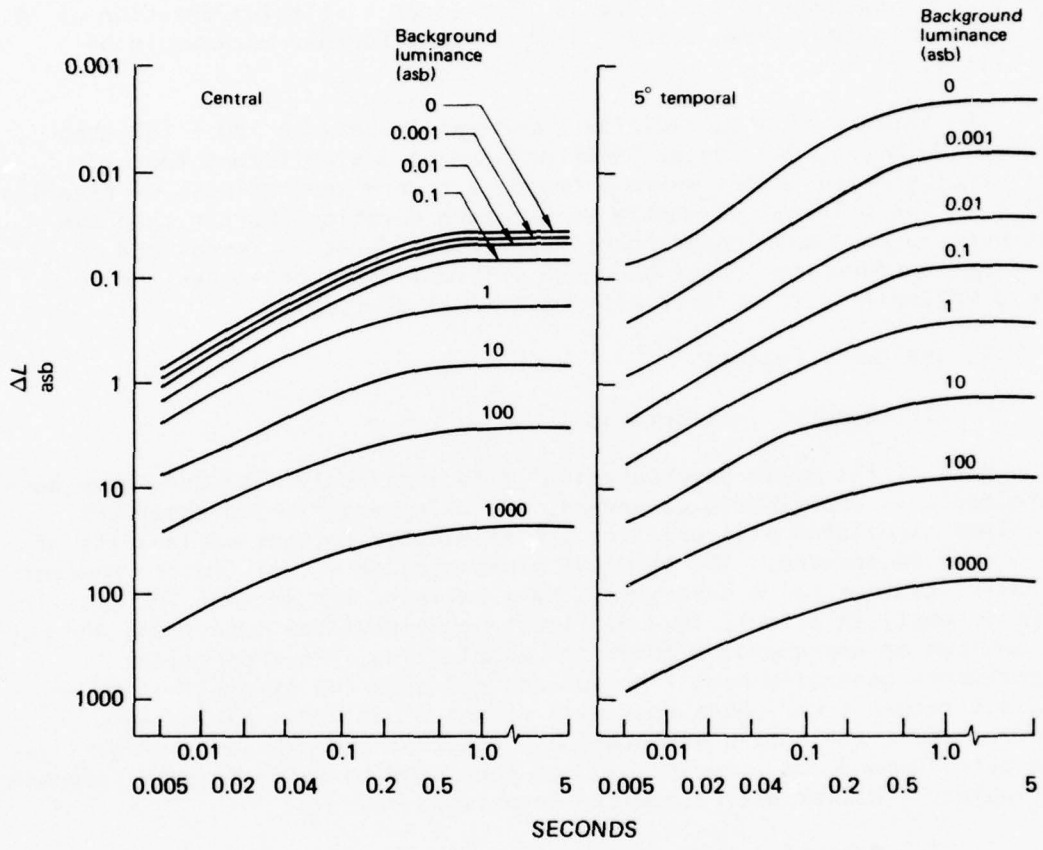

Figure 5. Increment threshold as a function of exposure duration for various background luminances in the fovea (left) and 5 degrees in the temporal visual field. (data from Dorff, 1953, and reprinted in Aulhorn and Harms, 1972, reprinted with permission)

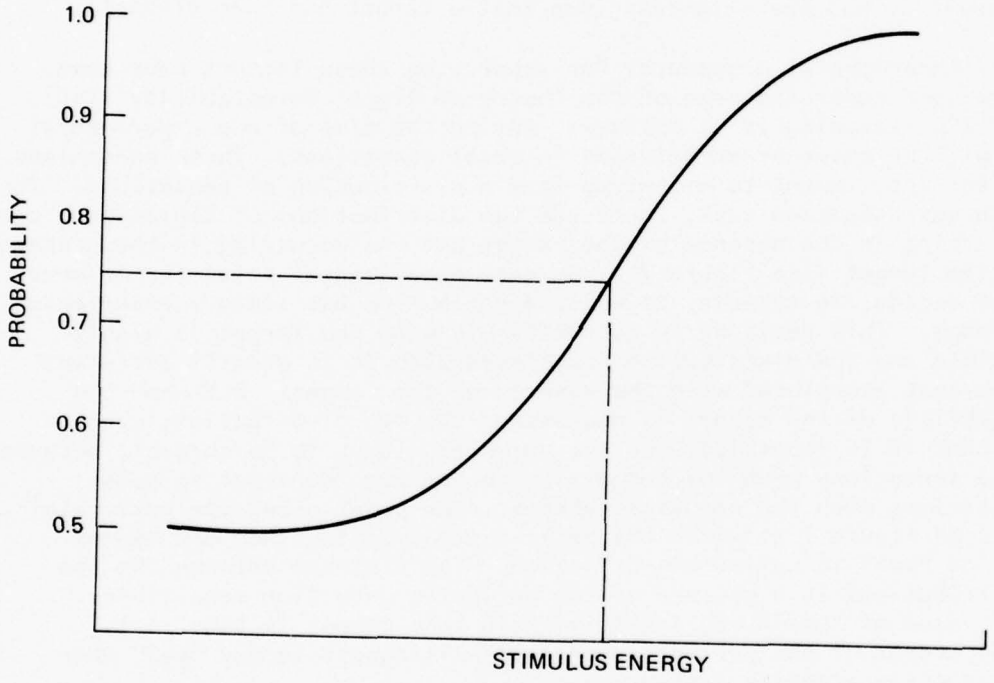

Figure 6. Detection probability as a function of stimulus energy for a two-choice (yes - no) detection task. Chance-level is 0.5.

3. Detection and Response Criterion

When a faint target is presented to a patient, two principal factors determine whether the patient will say that he saw it: (1) the detectability of the target, and (2) the patient's response criterion, i.e., his willingness to say "yes" when a target actually had been present. For the same stimulus energy, a patient who holds a strict criterion (who is unwilling to say "yes" until he is absolutely certain that he has perceived the stimulus) will appear to have a higher threshold than a subject who holds a relaxed criterion (who is willing to say "yes" whenever he has the slightest idea that a target had been present).

Experimental procedures for separating these factors have been developed under the name of the Theory of Signal Detectability (TSD). The TSD reasoning is as follows: During the time of one experimental trial, the observer experiences internal sensations. These sensations differ from moment to moment to form a distribution of sensations. In a target detection task, there are two distributions of sensations: one occurring in the absence of the target and one occurring in the presence of the target (see Figure 7). On each experimental trial the observer must decide, in essence, to which distribution his sensory experience belongs. This decision is not difficult when the target is highly visible and the distribution associated with it is greatly different from that associated with the absence of the target. But when the visibility of the target is decreased, the two distributions overlap so that it is impossible for the observer always to be correct, because some sensations when the target is present are identical to some sensations when the target is absent. The point along the horizontal axis of Figure 7 at which the patient stops saying "no" and begins saying "yes" is called his criterion. The distance between the two distributions is a measure of the patient's detection sensitivity. The value of specifying sensitivity in this manner is that it is independent of the patient's personal willingness to say "yes" when a target is actually present.

Another technique has also succeeded in distinguishing the contributions of sensory and response variables on the obtained value of threshold, namely, the forced-choice technique. It would provide a simpler and less laborious way of determining the visual field than the "yes" - "no" procedure described above. Research has demonstrated that visual thresholds are lower (indicating a purer measure of sensitivity) when obtained with forced-choice rather than the more conventional techniques such as the method of limits (Clark, Rutschmann, and Brown, 1963).

With either the spatial or temporal forced-choice, the observer is presented with comparison stimuli on every trial and must report which is "different." In the spatial case, the target and comparison stimuli are placed in different positions; in the temporal case, they are presented within two or more intervals of time separated by a given signal. Instructions to the observer include that he must choose one of the alternatives and guess when he is uncertain. This technique, thus, provides the tester with an accuracy indicator (he knows whether the

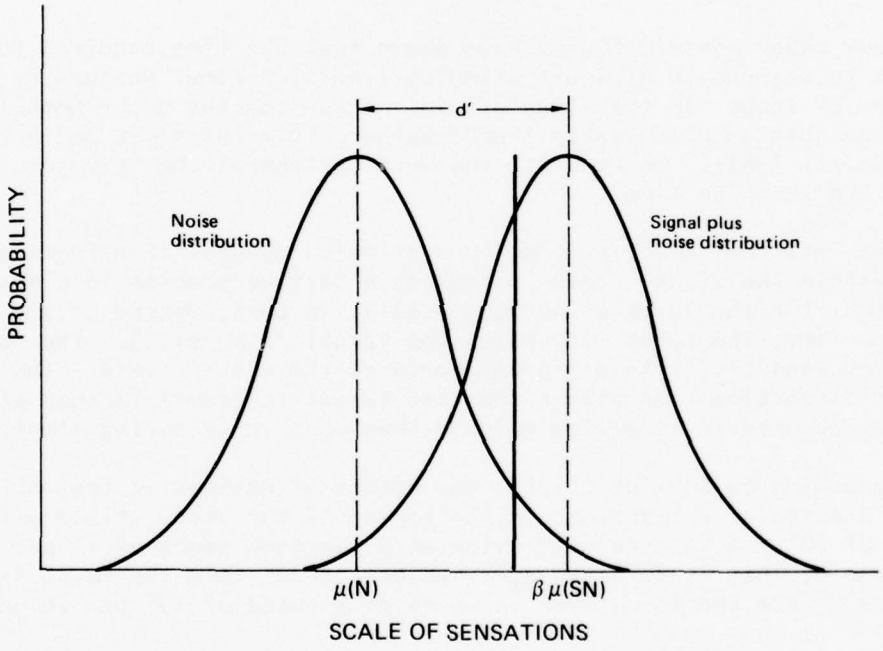

Figure 7. Probability distributions of a given sensation occurring on an experimental trial for noise alone and for a weak signal plus noise. The vertical line named β is the location of a criterion. The value of β is the ratio of the probabilities at the point where this line intercepts the noise and signal plus noise distributions.

observer guessed correctly or incorrectly) that is lacking in the more conventional psychophysical methods. This factor suggests that the use of a spatial forced-choice procedure in the measurement of the visual field yields a more stringent measure than that obtained by other means, while also considerably less costly in time and effort than the one provided by the statistical decision theory of signal detection. For an interesting application of the forced-choice technique to a clinical problem, see Theodor and Mandlecorn (1973). For more information on signal detection procedures, see Swets (1961, 1964, 1973) and Green and Swets (1974).

4. Reaction Time

Many experimental studies have shown that the time required for a subject to respond to a visual stimulus (reaction time) changes as a function of locus in the visual field. These changes occur both in light and dark adapted states (Poffenberger, 1912; Bartlett and McLeod, 1954; Rains, 1963). In general, the more peripheral the stimulus, the longer the reaction time.

The fact that reaction time to a stimulus changes as a function of locus within the visual field introduces a serious problem in kinetic perimetry, for the locus of detection will, in part, depend on the patient's reaction time, the speed with which the target is moved, and the rate of change of sensitivity in different parts of the visual field. The patient's reaction time allows the test target to travel farther after it is detected when it is moving quickly than when it is moving slowly.

According to Schmidt (1971), the effect of changes in test object speed is especially important in the region of the visual field with a radius of 30°. A test object moving at a constant speed of 1° per second, for example, that is detected by a subject at 20° from the fovea is only detected 5° from the fovea when it moves at a speed of 15° per second.

Fankhauser (1969) has related the speed of the test object, the combined reaction time of the patient and the clinician, the displacement of the isopter, and the diameter of the smallest detectable scotoma. These data are summarized in Figure 8 where one can easily estimate the effects of variations in the speed of the test object and the combined reaction time. Goldmann (1969), Duke-Elder (1962), and Dubois-Poulsen (1952) recommend a rate of movement in kinetic perimetry of 2° per second. Figure 8 shows that, although errors will be introduced by this speed, they are not large. Since reaction time is a major source of patient variability, constancy in target motion rate on the part of the examiner is desirable.

C. Clinical Variables

1. Target Blur

The problem of blur of the target's retinal image and the consequent apparent reduction in sensitivity has recently emerged as an important variable. Target blur resulting from high ametropia, posterior staphyloma, tumor induced forward movements of the retinal plane, retinal detachments, or serous retinopathy can cause pseudoscotomas or relative scotomas.

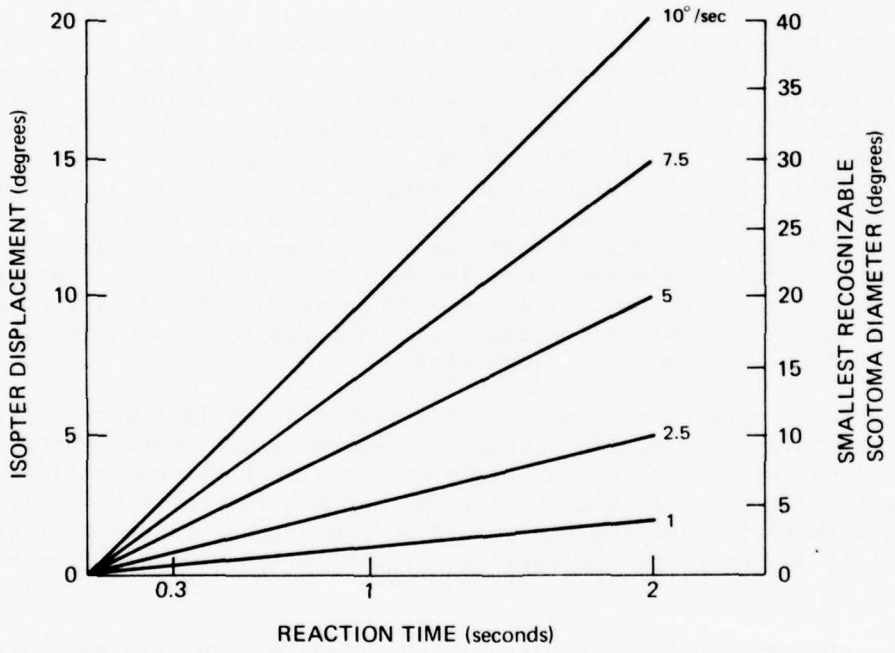

Figure 8. Displacement of an isopter and the smallest detectable scotoma diameter as a function of the reaction time and speed of the test object. (after Fankhauser, 1969, reprinted with permission)

(Schmidt, 1955). Sloan (1960), Ogle (1961), and Aulhorn and Harms (1972) have reported that refractive error increases detection thresholds only in central vision. Beyond 30° from the fovea, none of the studies reported any significant effect of target blur on detection. Other experiments, however, have reported that correcting peripheral refractive error results in lower thresholds for motion detection as far as 80° in the periphery (Leibowitz, Johnson, and Isabelle, 1972; Johnson and Leibowitz, 1974). Sloan (1960) also found that the effects of target blur were most serious for small targets (less than 12 minutes of arc in diameter). Targets larger than about 30 minutes of arc were unaffected by blur (3.0 diopters). Fankhauser and Enoch (1962) review this problem and demonstrate how data on blur may be used to define a relative retinal contour.

In short, in order to perform precise evaluations of sensitivity across the retina, blur of the retinal image must at least be minimized. The problem is that both the magnitude of the blur and the effect of blur on individual response varies markedly among individuals. Because of practical limitations of time, no practitioner is going to refract the retina point by point, and compromises are made during testing. Central fields should be determined using an optimal correction. When fine determinations of visual functions are to be made at other points in the field, it is suggested that the best spherical equivalent be provided at a representative point in the test area prior to evaluating function. This can be quickly determined by finding the lens providing greatest target clarity at the test point (and/or the lowest threshold) by coming from the "too much plus" side.

Thus, the effects on image quality caused by patient's refractive error, cycloplegic or miotic therapy, presbyopia, peripheral aberrations, and local variations in retinal plane of focus must all be considered when performing a visual field analysis. When using color stimuli, the chromatic aberration of the eye should be considered, since the ideal focal plane in the fovea may vary by as much as 1.5 diopters from red to blue.

The entrance pupil of the eye is the image of the iris aperture as seen through the cornea, and, since both the angular position of a target in the visual field and its angular size are specified relative to the entrance pupil, it should be emphasized that a corrective lens placed in front of the eye alters the entrance pupil. The closer a corrective lens is placed to the eye, the less the entrance pupil is displaced optically and the larger is the visual field available for testing through the correction. A record of entrance pupil diameter and refractive correction placed before the eye during visual field testing is, therefore, a desirable part of the test record. *

2. Pupil Size

Pupil size alters retinal illuminance, which in turn defines retinal adaptive state. Because of foreshortening, the effective pupil aperture is diminished in the periphery of the visual field. Figure 9 presents

* Vertex distance is an added useful parameter when lens corrections exceed 5D.

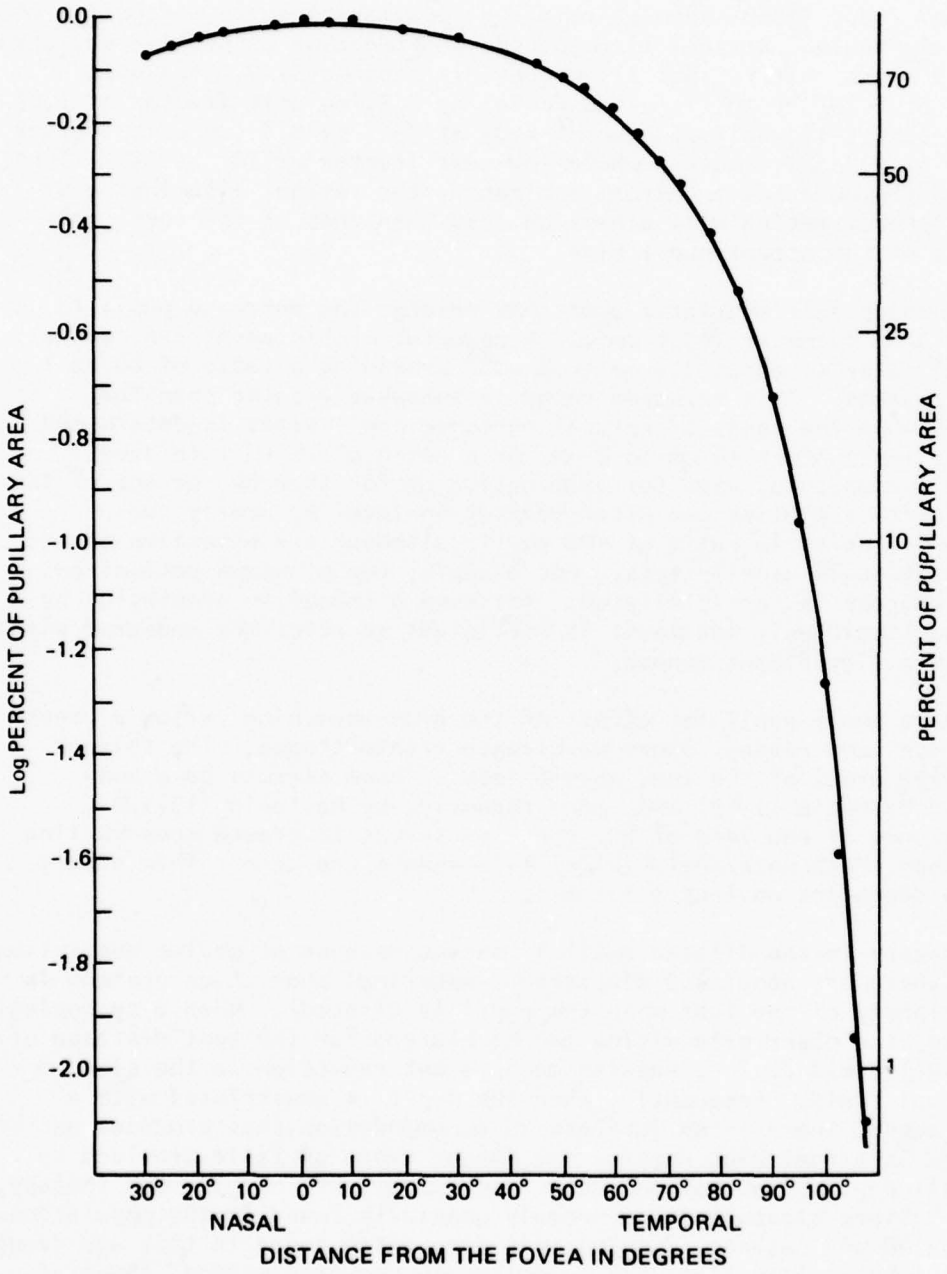

Figure 9. Percent of pupillary area relative to pupillary area at the point of fixation as a function of perimetric angle. (data from Jay, 1961)

the data of Jay (1960) showing relative pupillary area as a function of perimetric angle. Retinal illuminance is a function of pupil area, and Figure 9 shows that retinal illuminance is reduced by 0.1 log unit (factor of 1.25) at 50° from the fovea; by 0.2 log unit (factor of 1.6) at 66°; by 0.3 log unit (factor of 2.0) at 75°; by 0.8 log unit (factor of 6.3) at 93° and almost a whole log unit (factor of 10) at 95°. Thus, if the background has a uniform luminance, the retinal illuminance of the peripheral retina will always be less than that of the fovea, regardless of the actual pupil size.

A cycloplegic/mydriatic agent may enlarge the entrance pupil to about 9.0 mm diameter (63.6 mm^2). A powerful miotic agent can reduce pupil diameter to about 1.0 mm (0.8 mm^2) providing a ratio of 80 to 1 in pupil areas. This measured range is somewhat greater than that obtained when the range of natural entrance pupil sizes is determined by light level alone (2 mm to 8 mm, or a ratio of 16 to 1 in area). Thus, a cycloplegic, used for examination or for therapy, or one of the more effective miotics can alter adaptation-level by nearly two logarithmic units (a ratio of 100 to 1), although the effective change in adaptation is usually less. For example, the glaucoma patient on miotic therapy is rarely dilated. Yet even a change in adaptation by one logarithmic unit (or less) is sufficient to alter the measured visual field in a significant manner.

For a small pupil the effect of the blue-absorbing yellow pigment of the eye lens reduces short wavelength transmittance. The thinner peripheral areas of the lens absorb less. These effects have been measured by Weale (1953) and, more recently, by Mellerio (1971). Flourescence of the lens of the eye also serves to create some veiling glare when short wavelength (blue) illuminants are used. This effect is also dependent on lens thickness.

Imagery in the dilated pupil is poorer because of ocular aberrations (e.g., there are about 2.0 diopters of spherical aberration present in the periphery of the lens when the pupil is dilated). When a cycloplegic is added, the observer's vision may be blurred for the test distance of the visual field device, causing an apparent reduction in the size of the visual field. Frequently, when the pupil is constricted with a miotic agent, there is an increase in accommodation that produces an increase in target blur despite the larger depth of field provided by the small pupil, a phenomenon seen in many patients on glaucoma therapy. Further, since glaucoma is an anomaly generally found in the population over age 40 and cataract is also most frequently found in this age group, it is not unusual to find both anomalies in the same person. Some of the changes in visual fields described in the literature as accompanying ocular hypertension or early glaucoma can be interpreted as resulting from failure to control adaptation level and image quality in this clinical population (Forbes, 1966).

There are, of course, naturally occurring variations in pupil size in the population. For example, most clinicians are familiar with the widely dilated pupil of young myopic patients and the constricted pupil found in many presbyopic patients. By adjusting background luminance,

it is possible to compensate partially for a pupil size that is too small or too large, thus maintaining a relatively constant retinal illuminance for visual field testing.

3. Scattering Effects

A cataract scatters light and hence reduces the contrast between the test object and the background field. Thus, visibility is reduced and detection thresholds are raised. Other complications of cataract are light absorption, which may be spectrally selective since pigments in the lens may absorb some wavelengths more than others, and the development of increased myopia (or reduced hyperopia) due to lens swelling. The swelling may introduce additional image blur if the proper refractive correction is not provided during the test. Variations in the pupil size will enhance (large pupil) or reduce (small pupil) the contrast-reducing effect of a cataract.

Albino patients are also subject to glare effects because of transmission of light through the iris and walls of the eye and because of reflection and scattering within the eye.

4. Fixation

The accuracy of fixation is an important parameter during testing of the visual field. Unstable fixation will increase the variability of measurements, and shifted fixation will cause a displacement of measured isopters. Continuous monitoring of eye position with electro-oculographic (EOG) or infra-red scanning techniques would be ideal, but the expense and inconvenience (especially of EOG electrodes) often prohibits it. Direct observation of the eye by the practioner during testing using the telemicroscope that is provided on some perimeters (e.g., the Goldmann and the Harms) will give some indication of fixation steadiness, but continuous monitoring is inconvenient and cumbersome. Another technique requires the patient to monitor his own eye position. A target, large enough to just fill the blind spot, is positioned so that with proper fixation it is not visible. If fixation then deviates from the fixation point, the target becomes visible and serves as a warning to the patient. This system, which is provided on the Harms perimeter, is sensitive to deviations of a degree or so.

Mapping the blind spot gives an indication of fixation quality. If the spot is too small, unstable fixation is indicated. If it is not in the proper position, eccentric fixation may be the cause. Eccentric fixation may be further assessed by an ophthalmoscope with a reference grid, such as the Oculus Visuscope.® High refractive error also alters the apparent position of the blind spot. (See Fankhauser and Enoch, 1962).

When fixation is a problem because of unsteadiness, hemianopsia, or central scotoma, special procedures are called for. Surveillance of the patient with frequent rest periods can reduce variability. A reticle pattern (e.g., four lines, one to the left, one to the right, one above and one below, each pointing to the fixation point) surrounding the fixation point can also be helpful. Fixation can be improved by giving a fixation target to the second eye or by providing a fusable binocular pattern may also be necessary in extreme cases. See Sloan

and Feiock (1972) or Sloan (1971) for specific patterns.

5. Temporal Factors

When anomalies in the visual pathways exist - generally located in the optic nerve or more centrally - time-varying changes in visual sensitivity must be considered. Two classes of anomaly have been recognized. These are (a) an excessively rapid local adaptation to a visual stimulus and (b) a short-term saturation or visual fatigue-like effect. The latter seems to be the more commonly encountered problem.

A target stablilzed on the retina will disappear after a few seconds. In the peripheral visual field, even an unstabilized target will disappear if the eye is not moved. This fading is known as the Troxler effect. There are anomalies wherein targets seem to disappear too quickly, although more study of this effect is needed. Periodically flashing or revewing the stimulus returns the stimulus to visibility.

A second class of anomaly, which often had been thought to be caused by deficiencies in local adaptation, has recently been identified. This anomaly is a "short-term saturation or visual fatigue-like defect." (Enoch and Sunga, 1969) It is a loss of visual sensitivity when an individual is exposed to a visual stimulus for a time, whether the stimulus is flashing or not. Rest with eyes closed, lowered room lights, use of filters, and other similar techniques seem to help sustain vision in these cases. The effect may be present for both static and kinetic targets. This visual fatigue is quite different from a local adaptation anomaly (a failure to sustain excitation when a target is presented steadily).

The visual fatigue defect is revealed when performing static perimetry by repeatedly determining the threshold stimulus at the same retinal point (flashing or not flashing). The normal patient maintains a fairly steady threshold, the abnormal shows a clear reduction in sensitivity within a few minutes. If the defect is found only with a steady target, it is an anomaly of local adaptation. The latter can also be determined by comparing stimulus disappearance time of the patient with that of a normal observer at the same retinal locus.

In kinetic perimetry time-varying defects give rise to multiple, round scotomata, usually called a "swiss cheese" defect. If a perimetrist slows down when making an excursion into the field while examining these patients, the target tends to disappear. If he then goes over the area slowly, he finds a "relative scotoma." By carefully and slowly examining other parts of the field, he finds other relative scotomas within the area of involvement - these tend to be round because of the perimetrist's technique. The next time the field is tested, a whole new set of round relative scotomas are revealed, often having different field locations. It is the act of slowing down to make deliberate determinations rather than the presence of a stable defect that reveals the anomaly. These fields are often misinterpreted by the beginner.

Often, of course, these patients may have real, stable scotomata in addition to their visual fatigue anomaly, but the "swiss cheese" field defects are artifacts of the perimetric technique.

V. Clinical Perimetry

The goal of clinical perimetry is to measure detection sensitivity in different regions of the visual field. The locus of points in the visual field that have the same contrast sensitivity for a target of fixed angular size and exposure duration and for a fixed background luminance is called an isopter. A series of isopters, each representing a particular contrast sensitivity, form a topographic map of the visual field. At photopic levels of background luminance, highest sensitivity is normally found in the fovea, with sensitivity progressively decreasing into the periphery (see Figure 2).

Two general techniques for assessing visual field sensitivity are in use today: kinetic and static perimetry. Each has advantages and disadvantages that compliment each other, although static perimetry is the more scientifically rigorous.

A. Kinetic Perimetry

In kinetic perimetry, a target of fixed angular size and of fixed contrast with the background is moved from the far periphery toward the fovea along some meridian. At some point, the patient will detect the target, and the retinal locus at which this detection occurs is recorded. This procedure is repeated along many meridians (one might measure at meridians spaced 15 degrees apart). The line connecting all the detection loci defines the isopter for that particular target size and contrast. The contrast of the target is then changed (on a projection perimeter) and a new isopter determined. In this way, a series of isopters, each defining a different contrast sensitivity for a target of constant size are determined. Figures 10 and 11 present typical results for a normal left and right eye respectively. A target 10 minutes of arc in diameter was used against a background of 3.18 cd/m^2 (10 apostilbs). Sensitivity in the far periphery is low, so that target contrast must be high in order to be detected. The outer isopter in Figures 10 and 11 represents a contrast of 100, i.e, the target luminance is 1000 times greater than the background. As target contrast is successively reduced, it must come closer and closer to the fovea in order to be detected. The second isopter in Figures 10 and 11 represents a contrast of 10, an increase in sensitivity by a factor of 10. The other isopters represent contrasts of 3.2, 1.0, and 0.32. Under these test conditions a 10 minutes of arc target would have a threshold contrast of 0.10 at the fovea (see upper curve of Figure 2).

At eye clinics where these rigorous perimetric techniques are used (e.g. University Eye Clinic, Tübingen, Germany), all patients are examined by kinetic perimetry using one of the modern projection perimeters (e.g. the Goldmann or the Harms). First, a high contrast target is used to define the outer limits of the visual field. No set series of target

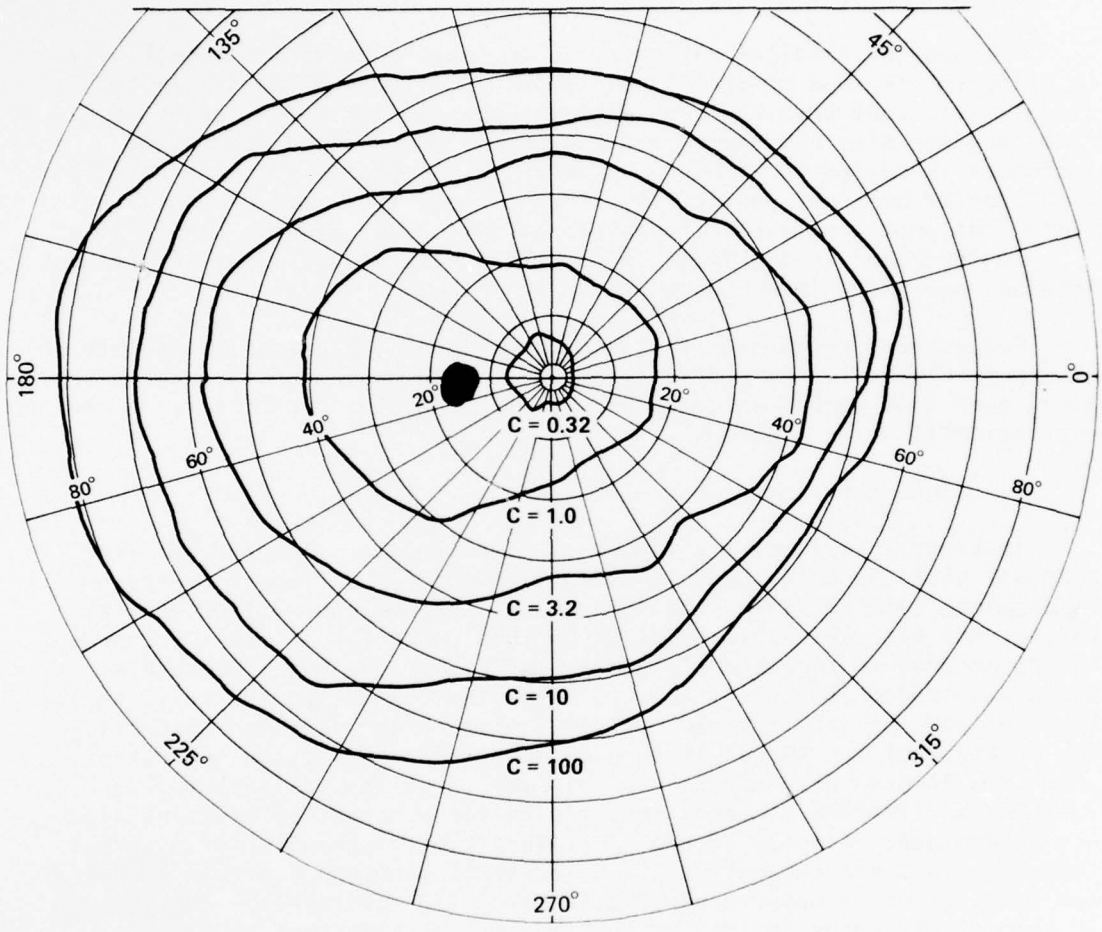

Figure 10. Normal kinetic visual field of the emmetropic left eye using a 10 min arc diameter test target viewed against a 3.2 cd/m^2 background. The threshold contrast ($\Delta L/L$), represented by each isopter, decreases toward the center: C=100, 10, 3.2, 1.0 and 0.32.

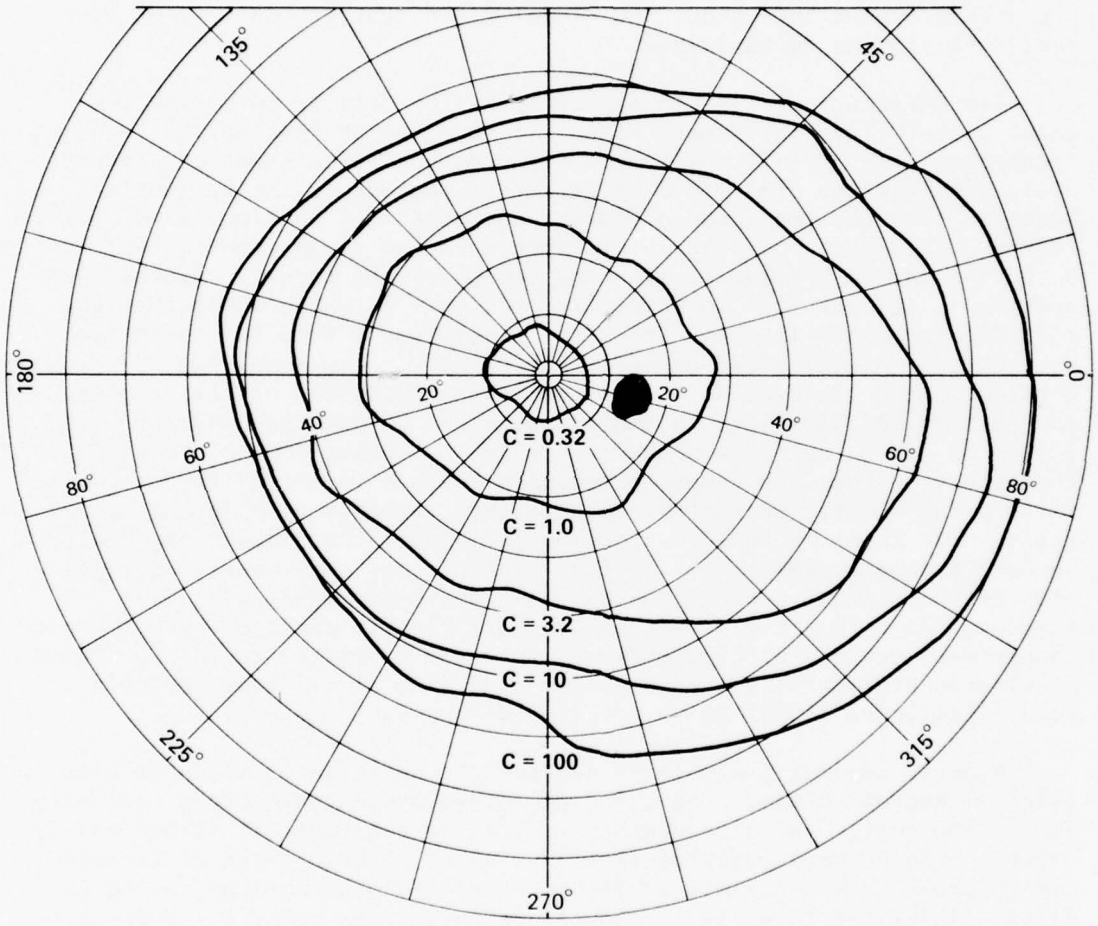

Figure 11. Normal kinetic visual field of the emmetropic right eye using a 10 min arc diameter test target viewed against a 3.2 cd/m^2 background. The threshold contrast (Δ L/L), represented by each isopter, decreases toward the center: C=100, 10, 3.2, 1.0 and 0.32.

contrasts are used for the inner isopters, but 0.5 log unit reductions are popular (the inner isopters of Figures 10 and 11 represent 0.5 log unit reductions of contrast). Near the center of the visual field, smaller contrast steps might be necessary in order to keep the isopters evenly spaced. If contrasts are chosen so that the measured isopters are evenly spaced throughout the visual field, the probability of detecting a scotoma is maximized.

The advantage of kinetic perimetry is its ability to survey the total visual field in a short time. It does suffer from several disadvantages that make it unsuitable for rigorous measurement of visual field sensitivity. The locus of detection depends on the patient's reaction time and the speed of target movement (see Section IV. C. 5.) Further, in kinetic perimetry, exposure duration is not controlled, and detection may be confounded with the motion of the target. Another problem is evident from an inspection of Figure 2, which shows that the contrast threshold is about the same (a "plateau") from 30° to 10° in the temporal visual field and from 20° to 10° in the nasal field. Thus a target whose contrast is just equal to the threshold of this region, moving from the periphery to the fovea, might be detected anywhere from 30° to 10° from the fovea depending on small fluctuations of sensitivity. The result is that the isopters measured in this "plateau" region of the field using kinetic perimetry can be highly variable even in the normal field. For lower photopic background luminances the problem is greater because the peak sensitivity of the fovea becomes more nearly equal to that of the plateau region (see curves c and d of Figure 2). The frequent claim that field defects are more readily detected with mesopic background (curve d of Figure 2) may be based partially on this artifact of kinetic perimetry, although target size is a significant variable here. See Greve (1973) for a detailed discussion.

Kinetic perimetry within 30 degrees of the fovea is often carried out using a tangent screen. The chief advantage of tangent screen perimetry is its low cost. One disadvantage is that target contrast is not easily varied. The current practice is to use white plastic disks as targets and to present them against a black or grey cloth background, although Frisen (1974) has recently introduced self-luminous targets. When using disks against a screen, target contrast is fixed and depends only on the reflectance of the target and the background. Typically this contrast is high ($C = 19.0$ for a white target of 0.80 reflectance presented against a black background of 0.04 reflectance). Because contrast is fixed, the size of the target must be varied in order to change target detectability. Large targets (i.e. 1 or 2 degrees) are detected in the periphery while small ones (i.e. less than 10 minutes of arc) must approach the fovea. Each isopter measured with a tangent screen is for a target of different angular size but of constant contrast; the isopters measured with a projection perimeter are often the inverse, targets of different contrast but constant angular size.

The relationship of tangent screen isopters relative to contrast sensitivity isopters determined in a quantitative perimeter is not simple because the summation properties of the retina vary with retinal locus

and because contrast threshold is not a linear function of target area (see Figure 3). In addition, adaptation conditions may be quite different. See Portney and Rubenzer (1972) for further comparison of tangent screen results with those of the Goldmann perimeter. The small tangent screen targets used to measure isopters near the fovea subtend angles much smaller than 10 minutes of arc (see Table 2). When using such small targets, the actual diameter of the image formed on the retina often is not a function of target size but of pupil diameter (see section IV.A.4). The effective contrast of these images may be reduced instead of their size on the retina. Interpretation of the tangent screen isopters near the fovea is difficult when one is not certain of the size of the target on the retina or its contrast with the background.

The current practice is to illuminate a tangent screen with an unstandardized light source. Often, 9 ft-candles is cited as standard, but no established standard exists. Further, this is an unsuitable unit of measurement. In order to evaluate the effective contrast of the target, the reflectances of the target disk and the background must be known. Assuming a background reflectance of 0.04 for a black background cloth, the resulting background luminance is 0.95 cd/m^2. This background luminance is well within the region where contrast threshold does not follow Weber's Law (Weber's Law: $\Delta L/L$ = constant). Given this situation, a change in pupil size or target luminance produces changes of response so that differences in tangent screen illumination found in various clinical setups will produce meaningful differences in measured visual fields. It is not surprising given the lack of calibration and regulation of luminances, that variations in tangent screen visual fields are often encountered. At higher adaptation levels, modest changes in pupil size or modest changes in calibration cause less marked response changes.

The above criticisms are aimed at the problem of interpretation of tangent screen isopters in terms of what we know about the basic contrast sensitivity in the human visual field and at the problem of reliability. The tangent screen procedure has clinical value in detecting abnormalities in the visual field. We seek to enhance its value.

B. Static Perimetry

The second clinical procedure for measuring sensitivity within the visual field compliments kinetic perimetry and overcomes some of its weaknesses. In static perimetry the target is kept fixed in size and retinal locus, and it is presented to the patient for a controlled exposure duration. The contrast required for detection of this target is usually measured by the ascending method of limits: Target luminance is increased from below threshold in a stepwise fashion until it is just detected. The target contrast is increased (in both the Goldmann and the Harms perimeters) by 0.1 log unit steps with each presentation, and the contrast at which detection occurred is noted. Steps of 0.05 log unit would be useful in special cases. The target is then moved to another retinal position and the procedure is repeated. A series of contrast thresholds are measured in this fashion along one meridian at, for example, two degree intervals and represents a sensitivity profile across the retina. Occasionally, data may be obtained at a series of points in a

circle of constant eccentricity from the point of fixation. Which meridian (or which eccentricity) is measured usually depends on the results of kinetic perimetry: It is chosen to pass through a region suspected of reduced sensitivity. Figure 2 shows a typical contrast sensitivity profile along the horizontal meridian using a 10 min spot against a 2.7 cd/m^2 (0.85 mL or 8.5 asb) background (upper curve). Sensitivity is greatest at the fovea and diminishes in the periphery. The lower curves represent the sensitivity with successive 1.0 log unit reductions (factor of 10) in the background luminance. One should note the drastic reduction of the peak foveal sensitivity relative to the near periphery that occurs at mesopic/scotopic luminance levels.

Summary. A goal of clinical perimetry is to assess detection sensitivity in the visual field. Static perimetry comes closest to a rigorous definition of sensitivity. Kinetic perimetry sacrifices rigor to gain more complete coverage of the visual field. The two techniques are thus complimentary, and, although they test somewhat different response properties, both provide information about detection sensitivity. Tangent screen perimetry, as currently practiced, is very useful clinically but suffers from a number of theoretical and practical limitations. Photopic backgrounds and the use of small targets are recommended with kinetic perimetry. It is desirable that a number of isopters should be determined and that angular size of the target, its contrast, exposure duration, and background luminance be controlled and recorded. Similarly, pupil size and viewing distance should be recorded and efforts should be made to minimize target blur at least in central vision.

C. Color Perimetry

A key question to be considered is whether perimetric examination with chromatic test objects can contribute information not obtainable by the use of white targets of varying size and of varying contrast with the background. There are two parts to this question. First, one is interested in distinguishing diseases that selectively affect cones as opposed to rods, and, second, in determining whether certain anomalies selectively affect the various classes of color vision detectors or color responses.

Previously in this document, stress was placed on the problem of specification of the stimulus: the need to define the hue, saturation, luminance, and wavelength composition of stimuli at the eye. This is only part of the problem. Color vision varies with adaptation level and with retinal position. Recent evidence (McCann and Benton, 1969; Trezona, 1970; Daw and Enoch, 1973) has suggested that in the retinal periphery, rods participate in color vision. The ability to discriminate color diminishes with retinal eccentricity (Cruz and Moreland, 1955; Weale, 1953).

While most diseases affect both rods and cones, some anomalies influence rod vision earlier and more profoundly, and others selectively impair cone function (Sloan and Feiock, 1972; Sloan and Brown, 1962; François, Verriest, Rouck, and Humblet, 1956). Since most perimetric

examinations are conducted at modest photopic levels, specific rod involvement may not be detected, and the rare cone-specific anomalies may be missed with white stimuli because rod response takes over, giving evidence only of some alteration in retinal sensitivity. Rushton (1968) has demonstrated that if only limited retinal (or vitamin A, or visual pigment precurser) is present, cones will be favored, largely because of their more rapid recovery from substantial bleaching.

When testing color fields, certain problems are encountered. Since it is difficult to obtain pigments that reflect or transmit narrow bands of wavelengths, many filters and all papers and painted targets only favor or bias one set of cone receptors over another, and a definitive test is rarely obtained. Further, it is necessary to distinguish the nature of the response obtained carefully: Whether it was the response to the hue or to the brightness of the target, for example. Ferree and Rand were pioneers in color perimetry and stimulus specification. They used large targets having the same luminance as the grey background field. Thus, they tried to minimize the brightness of the test target as a variable in order to emphasize its chromatic properties. However, if there is a protan deficiency, the red target would tend to look dark against the gray background.

In order to distinguish color properties, care must be taken in choosing responses. Color naming is always difficult in congenital anomalies but is significant in acquired lesions. A monochromat, whose visual properties were extensively studied (Daw and Enoch, 1973) and who was revealed to have only rods and blue cones, could invariably correctly distinguish the two ends of a large (several degrees) spectral display as "blue and yellow." He had little sensitivity in the red. This raises another issue, stimulus size. Failure to make distinctions for one target size need not predict failure for other target sizes when testing color anomalies.

Returning to test parameters employed, the observer may be asked to perform color matching, i.e. match the hue, saturation, and brightness of a test target with that of a reference target located either at fixation or at some fixed distance from fixation. The patient may be instructed to make a hue discrimination, i.e., to respond when the color of the test object changes. Another test procedure coming into use is what might be termed the "chromatic static." Here the increment threshold is measured for one wavelength, while the background is illuminated using a stimulus of different wavelength composition. Stiles has been able to isolate a number of basic color mechanisms by selective chromatic adaptation and by measuring the response of the remaining most sensitive mechanism (Enoch, 1972; Wald and Wooten, 1973). A strong yellow adapting background field will selectively reduce (light adapt) the sensitivity of the red and green systems and only minimally influence the blue mechanism. If an appropriate blue test target is then applied on the yellow background, the response of the blue system may be selectively sampled. Verriest and Israel (1965) and Hansen (1974) have performed studies of these effects using a quantitative perimeter.

As implied above, chromatic judgments are significantly influenced by target size. Smaller targets are more influenced by blur. When using colored test targets, it should be remembered that there is about 1.5 diopters of chromatic aberration in the eye (consider the red-green or duochrome tests used to refine refraction). Blue sensitivity, as such, for small targets is generally reduced and is lacking in the fovea centralis. Thus, in general, larger targets are used when making color analyses.

Last, there is a problem when testing color anomalies in that virtually all our tests have been defined for congenital defects rather than for acquired anomalies. Recently, a new organization, The International Research Group on Colour Vision Deficiencies, has been formed in order to try to attack problems dealing with the analysis of acquired color defects. New tests are needed, particularly tests applicable at early stages of disease.

D. Receptive Field Perimetry

Our knowledge of the functional organization of the retina and visual pathways have advanced rapidly during recent years. The receptive field of a neuron is defined as that retinal area within which appropriate visual stimulation causes a change in the activity of the neuron. Westheimer (1965, 1967) developed a psychophysical procedure that gives results that seem to reflect the properties of retinal ganglion cell receptive fields (i.e. circular and antagonistic).

Enoch, Sunga, and co-workers (Enoch and Sunga, 1969; Sunga and Enoch, 1970a, 1970b; Enoch, Sunga, and Bachmann, 1970a, 1970b; Enoch, Berger, and Birns, 1970a, 1970b) have adapted Westheimer's technique as a clinical test. The test itself is a modified test of spatial summation. A small (e.g. 3-6 minutes of arc) constant diameter test field is set at a fixed suprathreshold luminance at the locus in the visual field that is to be tested. This field is flashed at a rate of about one per second and is easily detectable. It is superimposed on the fixed background hemispherical field of a quantitative perimeter. A second continuous field is then centered on the small flashing field. The diameter of continuous field is then centered on the small flashing field. The diameter of the second field is varied in steps from almost equal to the flashing spot to several degrees in diameter. At each diameter, the luminance needed in that field in order to make the small flashing field disappear and reappear is measured. Plotting area (or diameter) of the second field, which is variable in size, against threshold yields a three-part function (see Figure 12).

For small areas of the second field, there is complete summation; that is, doubling the area of the second field reduces by half the luminance of that field needed to make the flashing test field disappear. Beyond a certain critical second field diameter, the process reverses and more light is needed to bring the flashing field to threshold as the field size increases. Finally, the function approaches an asymptote. The

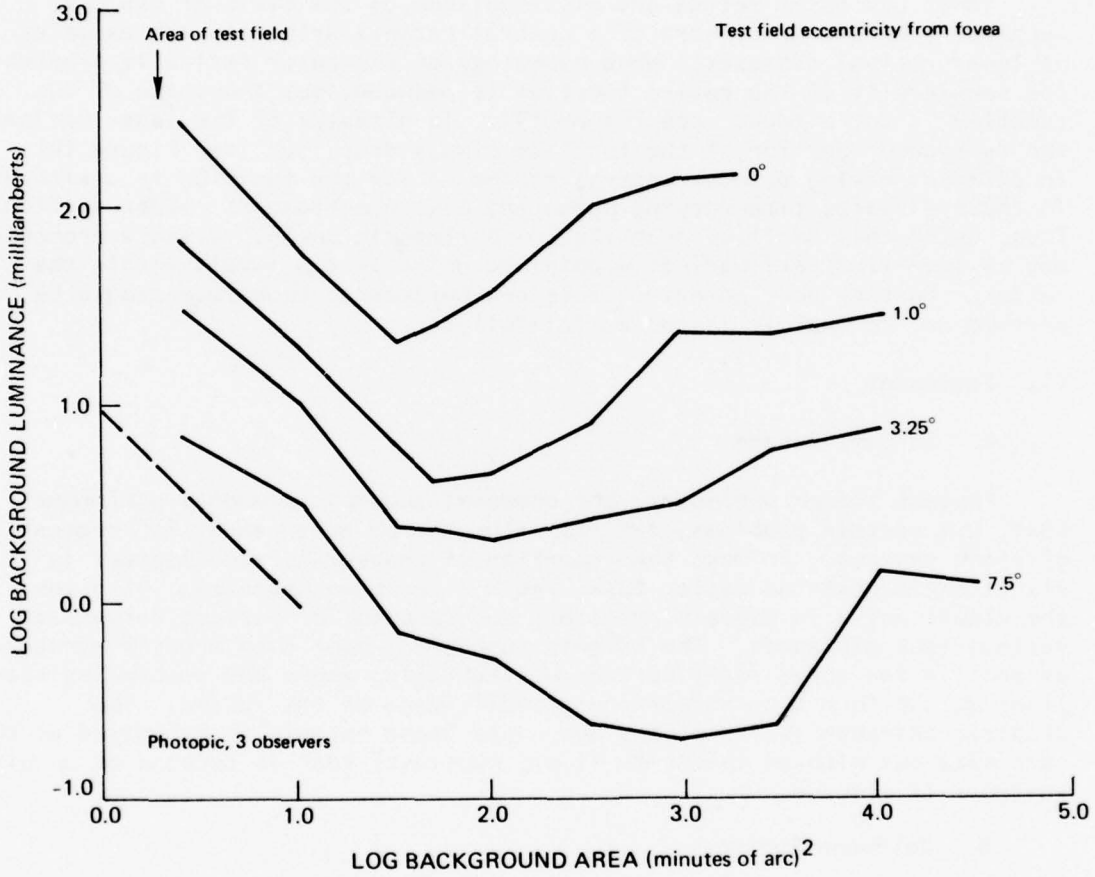

Figure 12. Background luminance required to keep test spot at threshold as a function of background size for four different retinal loci, with photopic vision. Test field luminance was set at 1.5 log units above absolute threshold and was flashed at a duration of 14 msec. Note that summation area and inhibition area increase as a function of retinal locus. (from Enoch, Sunga, and Bachmann, 1970, reprinted with permission)

first part of this function (summation-like) acts as the "center" of a ganglion cell receptive field, the second part is similar to the "surround" of a receptive field, and the asymptotic region acts as if the stimulus area has exceeded the effective bound of the receptive field.

Inner and outer retina are distinguished on the basis of vascular supply. Glaucoma or closure of a central retinal arteriole are examples of inner retinal diseases. When pathology of the outer retina is present, the sensitivity of the entire function is reduced, but the shape of the function is not altered (see Figure 13). In diseases of the inner retina, the "surround" portion of the function simply drops out (see Figure 14). In diseases having a locus central to the retina the function is unaltered. In these diseases time-varying phenomena make measurements rather difficult. Thus, using this modified quantitative perimetric method, disease processes may be localized perimetrically point by point at two levels within the retina. Further development of this new perimetric technique should be carried out to exploit its potential fully.

VI. Equipment

A. Tangent Screen

Tangent screen perimetry, the cheapest and most commonly performed test, has certain problems, but its value can be enhanced by improvement of light sources. To make the reporting of tangent screen isopters in visual angle units an easier task, Table 2 has been prepared. It gives the visual angle in degrees, minutes, and seconds, of various targets at various test distances. The targets subtending less than about 6 minutes of arc (in the upper right portion of the table, above the descending stepped line) do not form a correspondingly small image on the retina. The dioptric characteristics of the eye cause these targets to be imaged as the same size but with an intensity (i.e., contrast) that is reduced as angular subtense is reduced.

B. Goldmann Perimeter

The Goldmann perimeter was designed by Dr. Hans Goldmann to meet the requirements of rigorous quantitative perimetry.

The Goldmann instrument is not quite as flexible as the Harms/Aulhorn perimeter but is much less expensive and, hence, is more widely used. It has a hemispherical dome 30.0 cm in radius, which is set at a luminance of 10.0 cd/m^2 (3.15 mL or 31.5 asb). Six different sizes of targets, slightly elliptical (the effect of multiple mirrors in the projection train), can be projected on the dome. The targets are arranged so that each one has four times the area of the next smaller one. Table 3 presents these targets with the diameter, in minutes of arc, of a circular target of equal area. Slightly elliptical targets provide a contrast threshold equivalent to that of a circular target of equal area.

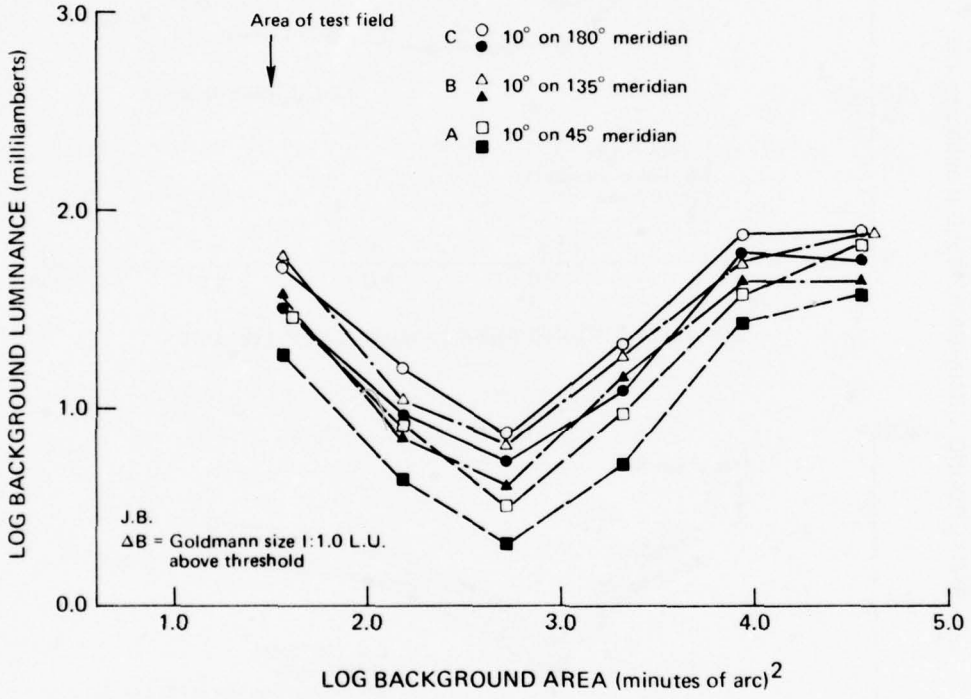

Figure 13. Westheimer functions with disease of the outer retina. Data were obtained in a patient with nonspecific choroiditis within the normal field (A) and within the scotoma area (B and C). All three curves show normal summation and inhibition. (from Sunga and Enoch, 1970, reprinted with permission)

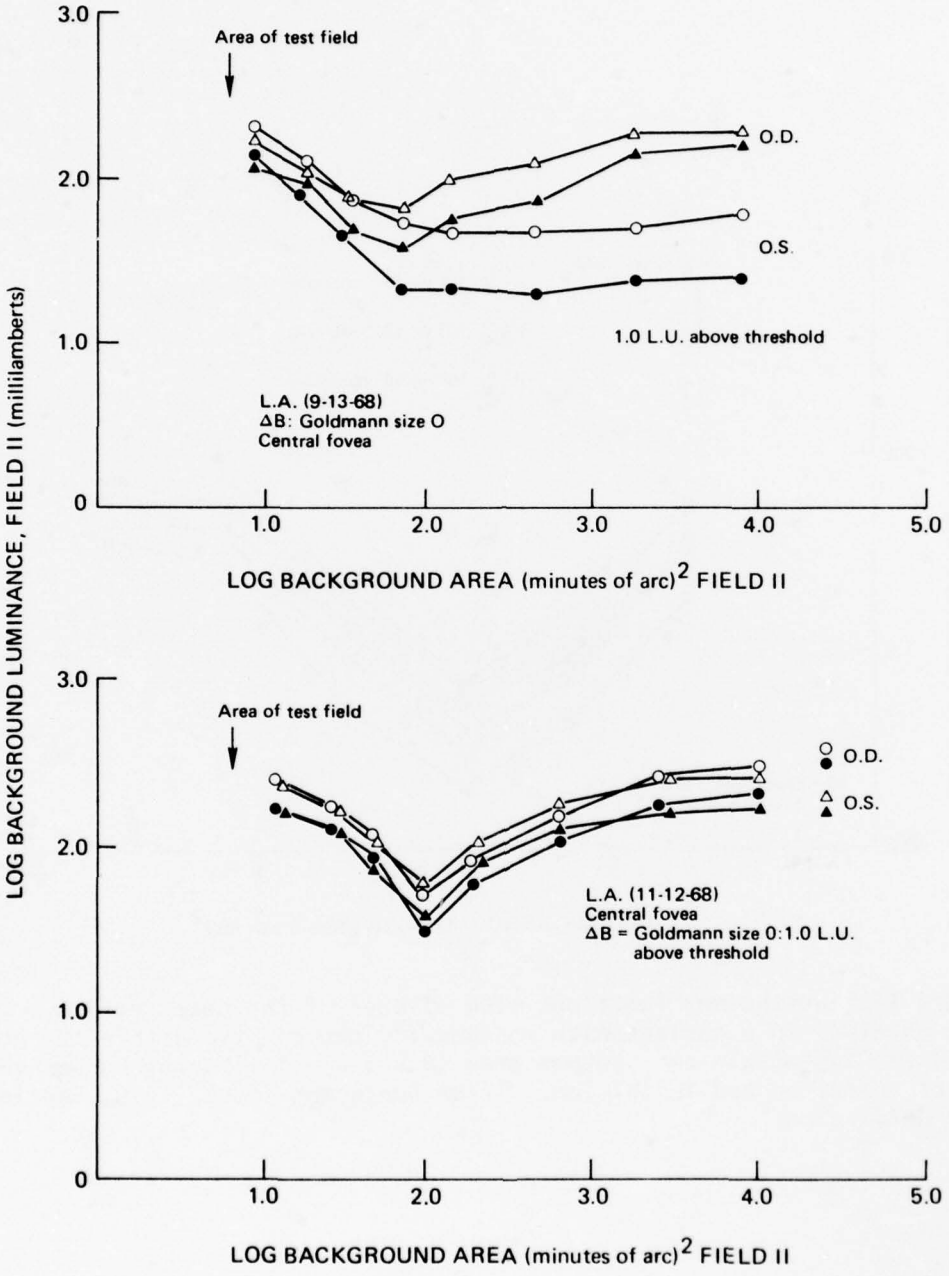

Figure 14. Westheimer functions with disease of inner retina. Data show loss of the surround part (inhibition arm) of the function in the left eye of a patient with macular edema following photocoagulation of a choroidal angioma temporal to the macula (top). Botom graph shows recovery of the inhibition three months later. (from Sunga and Enoch, 1970, reprinted with permission)

Table 2. Visual angle subtended by various tangent screen targets presented at various viewing distances. *

Target Size (mm)	Viewing Distance (mm)						
	330	500	1000	1500	2000	3000	4000
0.50	5' 13"	3' 26"	1' 43"	1' 9"	52"	34"	26"
0.63	6' 34"	4' 20"	2' 10"	1' 27"	1' 5"	43"	32"
1.0	10' 25"	6' 53"	3' 26"	2' 18"	1' 43"	1' 9"	52"
1.5	15' 38"	10' 19"	5' 9"	3' 26"	2' 35"	1' 43"	1' 17"
2.0	20' 50"	13' 45"	6' 53"	4' 35"	3' 26"	2' 18"	1' 43"
3.0	31' 15"	20' 38"	10' 19"	6' 53"	5' 9"	3' 26"	2' 35"
4.0	41' 40"	27' 30"	13' 45"	9' 10"	6' 53"	4' 35"	3' 26"
5.0	53' 5"	34' 23"	17' 11"	11' 28"	8' 36"	5' 44"	4' 18"
10.0	1° 44' 10"	1° 8' 45"	34' 23"	22' 55"	17' 11"	11' 28"	8' 36"
20.0	3° 28' 21"	2° 17' 31"	1° 8' 45"	45' 50"	34' 23"	22' 55"	17' 11"
30.0	5° 12'	3° 26' 16"	1° 43' 8"	1° 8' 45"	51' 34"	34' 23"	25' 47"
40.0	6° 56'	4° 34'	2° 17' 31"	1° 31' 40"	1° 8' 45"	45' 50"	34' 23"

* For explanation of stepped line, see text.

Four target luminances at 0.5 log unit intervals give target contrasts of 31.5, 10, 3.15, 1.0. Instruments equipped for static perimetric testing allow variation of target luminance in 0.1 log unit steps. The target notation on the Goldmann is arbitrary and a bit confusing. Targets 4e and 3e differ in luminance by 0.5 log unit, and targets 4e and 4d differ by 0.1 log unit. Target 4e has the highest luminance (318.3 cd/m^2, 100 mL, or 1000 asb). The shutter is set so that very brief exposures are not possible. A flicker attachment and special fixation devices are available on some models. In order to measure the foveal visual field, a special fixation projector is used, and the test array shifted in the perimeter telescope is used to monitor eye movements.

Table 3. Equivalent angular diameter and area of the Goldmann perimeter targets.

	Target Diameter and Area		
Target	Target Area	Diameter* Minutes of Arc	Area* Squared Minutes of Arc
0	1/16 mm^2	3.24'	8.24 sq. min. arc
I	1/4	6.46'	32.77
II	1	12.90'	130.7
III	4	25.86'	525.3
IV	16	51.72'	2,100.0
V	64	102.40'	8,238.0

*Equivalent round target, located 30 cm from the center of the entrance pupil of the eye.

C. Harms/Aulhorn Perimeter

The Harms/Aulhorn or Tübingen perimeter was designed by Drs. H. Harms and Elfriede Aulhorn of the University Eye Clinic in Tübingen, Germany. The Harms/Aulhorn perimeter is more versatile than the Goldmann but more expensive. It has a hemisphere 33.0 cm in radius. The background luminance can be varied from 3.183 to 3.183×10^{-6} cd/m^2 (1.0 to 10^{-6} mL or 10 to 10^{-5} asb) in 0.5 log unit steps. Circular targets ranging in diameter from 7 min. (38.5 sq. min.) to 114 min. (10,211 sq. min.) as well as a series of square targets of equivalent area can be selected by turning a dial. The luminance of the test target may be varied from 318.3 to 3.183×10^{-8} cd/m^2 (100 mL to 10^{-8} mL, 1000 apostilbs to 10^{-7}asb) in 0.1 log unit steps. A solenoid shutter allows exposure durations of 100 msec or more. Thus, a wide range of target contrasts, background luminances, and target sizes are available. A gearing system allows the record chart to represent either the whole visual field or just the central field (out to 30° from the fovea).

D. Automation

Automation of perimetric and visual field testing may be regarded from different points of view. (1) Perimetric examinations take time and skill. By using automation or semi-automation, more people may be tested by less skilled practitioners so that highly skilled practitioners may be reserved for an interpretive role and for advanced and detailed test analyses. (2) Through automation, the delivery of test stimuli can be standardized, and the variability in test administration can be reduced. (3) Automated or semiautomated testing procedures are valuable for screening of large numbers of individuals. (4) Last, these same techniques can be programmed for multiple simultaneous stimulus target presentation, which might speed data acquisition and help test certain pathological states where visual sensitivity in certain parts of the field varies in the presence of other stimuli. For example, the latter phenomenon (extinction) often occurs in lesions of the parietal lobe of the brain.

The design of automated or semi-automated visual field testing equipment will depend on which of the above uses will be served by the equipment. How much of the procedure is to be automated, and what will be the role of the individual operating the device? Many trade-offs must be considered, including cost and examiner training time (both in school and office). If a technician serves as examiner, should he merely be present, locate the patient's head properly in the headrest, read instructions to him, and change data sheets? Will the technician also monitor the patient's alertness at the task and his steadfastness of fixation and record the spectacle correction?

Different anomalies alter the visual field or visual response parameters selectively. Hence the nature of the test program may change with the problem as well as with the selection of the patient population. Automated testing may substantially increase patient examination time if a pre-programmed examination is too general, that is, not specific for the patient's problem. Or, on the contrary, if the set program of presentation is too limited in scope, there is the risk of missing a significant but localized lesion. Some of these questions are considered by

Fankhauser, Koch, and Roulier (1972) and Koch, Roulier, and Fankhauser (1972).

The complexity of the patient's task must be considered. For example, the response capabilities and reaction times of elderly, infirm patients differ from those of applicants for driver's licenses and from those of a school population. Similarly, educational and cultural background are important in defining a test task.

The necessary technical skills required for implementation of desired automation schemes already exist in large measure. Visual-field response may be studied subjectively, by asking the patient to respond when he sees projected stimuli, or objectively, by employing electrophysiological recording techniques. Fixation stability may be monitored by means of eye movement devices. Responses may be recorded and related to the delivered stimulus by logic circuitry. Stimuli may be preprogrammed for delivery, and test-retest reliability determined. Responses may be printed out and compared with templates defining normal or abnormal responses or stored for reference in a data bank. Classical perimetric devices may be modified for use, or a computer-driven cathode ray tube system may be utilized.

The problem in automation is, therefore, primarily a matter of defining the task from clinical, social, manpower, and economic points of view. But whatever the purpose of an automated perimetric system, its value in defining visual sensitivity will be greatly compromised if the important variables discussed in previous parts of this report are not controlled: target contrast, angular size, background luminance, exposure duration, patient reaction time, fixation, spectacle corrections, and pupil size. The knowledge of these variables gained through research using quantitative perimeters should be used in the design of automated perimeters. Many talented researchers are working on automated techniques. They include Friedmann, Aulhorn, Fankhauser, Spahr, Greve, and Lynn.

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13. ABSTRACT

The report makes the following recommendations: (1) That photometric standards for visual field test equipment be expressed in luminance units; that the illuminant and its desired operating characteristics be specified by the manufacturer for each visual field testing device; (2) That in the specification of chromatic stimuli, the wavelength composition of the stimulus reaching the eye and the C.I.E. (Commission International de l'Eclairage) chromaticity coordinates be given; (3) That background field luminance, test target parameters /target luminance, size (area), configuration, and exposure duration or rate of translation/, viewing distance, and location of a target in the visual field be specifiable; (4) That office, field, and screening instruments design incorporate test parameters that produce relatively stable response states.

The report also contains a review of basic data and concepts for measurement of visual fields.

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